U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-267 931

Preparations for Acquisition of Baseline Emissions Data From Gasoline Powered Trucks Above 10,000-lb. GVW

Southwest Research Inst, San Antonio, Tex

Prepared for

National Center for Air Pollution Control, Ann Arbor, Mich Procedures and Emissions Background Development Section

Jun 68

PB 267 931

PREPARATIONS FOR ACQUISITION OF BASELINE EMISSIONS DATA FROM GASOLINE POWERED TRUCKS ABOVE 10,000-LB GVW

INTERIM REPORT

Karl J. Springer
Glenn L. Williams

SPECIAL REPORT

Prepared for

Procedures and Emissions Background Development Section
Motor Vehicle Research and Development Program
National Center for Air Pollution Control
Contract No. PH 86-67-72
U. S. Public Health Service
Department of Health, Education and Welfare

June 1968

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO HOUSTON

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Preparations for Acquisition of Baseline Emissions Data from Gasoline Powered Trucks Above 10,000-lb GVW			5. Report Date June 1968 6.
7. Author(s) Karl J. Springer and Glenn L. Williams			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Southwest Research Institute 8500 Culebra Road San Antonio, Texas 78228			10. Project/Task/Work Unit No. 11. Contract/Grant No. PH 86-67-72
12. Sponsoring Organization Name and Address Procedures and Emissions Background Development Section Motor Vehicle Research and Development Program National Air Pollution Control Administration Ann Arbor, Michigan 48105			13. Type of Report & Period Covered Interim Report 14.
15. Supplementary Notes			

16. Abstracts: The overall objective of this study is to obtain baseline emissions data from gasoline powered trucks using experimental, "second generation" type procedures. To acquire the baseline emissions data required a substantial preparations phase involving further development of chassis dynamometer cycles, the design and construction of a truck version of the PHS Variable Dilution Sampler, and the establishment of correlation with previous program procedures, and different exhaust sampling schemes, are necessary. This interim report reviews and describes these preparations and procedures. The preparations phase for the given classification of trucks includes two major objectives: 1) to establish the relationship between emissions obtained on the SwRI chassis dynamometer and that obtained by the Ethyl Corporation; 2) to confirm and establish correlation of exhaust gas sampling by the servoproportional sampling system and variable dilution sampling system.

17. Key Words and Document Analysis: 17a. Descriptors

Air Pollution
Motor Vehicles
Exhaust Gases
Trucks
Data Acquisition
Sampling
Preparation

17b. Identifiers/Open-Ended Terms

Emissions Data
Preparations Phase

17c. COSATI Field Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Available from NTIS, Springfield, VA. 22161	UNCLASSIFIED	67
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

SOUTHWEST RESEARCH INSTITUTE
8500 Culebra Road, San Antonio, Texas 78228

PREPARATIONS FOR ACQUISITION OF BASELINE EMISSIONS DATA FROM GASOLINE POWERED TRUCKS ABOVE 10,000-LB GVW

INTERIM REPORT

Karl J. Springer
Glenn L. Williams

SPECIAL REPORT

Prepared for

**Procedures and Emissions Background Development Section
Motor Vehicle Research and Development Program
National Center for Air Pollution Control
Contract No. PH 86-67-72
U. S. Public Health Service
Department of Health, Education and Welfare**

June 1968

Approved:

John M. Clark, Jr.

John M. Clark, Jr., Director
Department of Automotive Research

TABLE OF CONTENTS

		Page
LIST OF ILLUSTRATIONS		iii
LIST OF TABLES		iv
I.	INTRODUCTION	1
II.	OBJECTIVE	4
III.	SAMPLING AND ANALYSIS EQUIPMENT, INSTRUMENTS, AND PROCEDURES	5
	A. Continuous Sampling and Analysis	5
	B. PHS Servo Proportional Exhaust Sampling System	5
	C. PHS Variable Dilution Sampling System	8
IV.	VEHICLE OPERATING PROCEDURES	17
	A. Proposed 1970 Federal Heavy-Duty Gasoline Truck Dynamometer Cycle	17
	B. Experimental Truck Dynamometer Cycles	17
V.	EMISSIONS RESULTS	22
	A. Correlation of Experimental Cycle Results with DLA Road Course Data	22
	B. Correlation of Variable Dilution with Servo-proportional Sampler Results	30
	C. Proposed Constant Speed Federal Cycle Results Via Continuous and Variable Dilution Sampling	38
VI.	SUMMARY AND CONCLUSIONS	42
REFERENCES		44
APPENDICES		45
	A. Class III Truck Exhaust Emissions Results	45
	B. Class IV Truck Exhaust Emissions Results	53

LIST OF ILLUSTRATIONS

Figure		Page
1	Continuous Sampling and Analysis Instrumentation System	4
2	PHS Proportional Sampling System: Bag Box Servo and Operation Console Shown	6
3	PHS Proportional Sampling System Laminar Flow Element - Transducer Installed	7
4	Bag Samples of Vehicle Exhaust Analyzed by Flame Ionization and Nondispersive Infrared Methods	8
5	Variable Dilution Sampling System Schematic	10
6	Variable Dilution Sampler - Front View	11
7	Variable Dilution Sampler - Rear View	12
8	Variable Dilution Sampler - Right End View	13
9	Exhaust Inlet Cone for Use with Truck Version PHS Variable Dilution Sampler	14
10	Typical Gasoline Powered Truck Prepared for Emissions Sampling by PHS Proportional and Variable Dilution Methods	16
11	Effect of Road Load Dynamometer Setting on Class III 1968 Van Truck Emissions - Experimental Nine-Mode Cycle	33
12	Effect of Road Load Dynamometer Setting on Class IV 1967 Stake Truck Emissions - Experimental Twelve-Mode Cycle	37

LIST OF TABLES

Table		Page
1	Proposed 1970 Test Procedure Heavy-Duty Vehicles Dynamometer Operation Cycle	18
2	Experimental Class III Gasoline Truck Chassis Dynamometer Cycle	19
3	Experimental Class IV Gasoline Truck Chassis Dynamometer Cycle	21
4	Comparison of Nine-Mode Experimental Cycle at Various Load Conditions to Road Course Emissions	24
5	Comparison of Twelve-Mode Experimental Cycle at Various Load Conditions to Road Course Emissions	27
6	Comparison of Twelve-Mode Experimental Cycle at Various Load Conditions to Road Course Emissions	29
7	Class III Gasoline Powered Truck Twelve-Mode Experimental Cycle Emissions	31
8	Comparison of Twelve-Mode Experimental Cycle at Various Load Conditions to Road Course Emissions	35
9	Class IV Gasoline Powered Truck Twelve-Mode Experimental Cycle Emissions	36
10	Proposed 1970 Federal Standard Heavy-Duty Gasoline Truck Cycle Emissions	39
11	Comparison of Variable Dilution Sampling and Analysis Results	41

I. INTRODUCTION

The gasoline powered truck comprises about 10% of the total vehicles and burns approximately 25% of the gasoline consumed in the United States. A great deal of emissions data has been published on automobiles, but there is a significant lack of published emissions data from trucks. For this reason, the U. S. Public Health Service's National Center for Air Pollution Control initiated a study with Southwest Research Institute to acquire baseline emissions data. Because of the lead time requirements and the need to acquire baseline emissions data with "second generation" test procedures, the SwRI program was concerned mainly with emissions from vehicles operated on experimental chassis dynamometer cycles. The experimental cycles employed basically were those developed by an earlier U. S. PHS sponsored study at Ethyl Corporation and described in their final report[1]*. In addition to the use of experimental cycles which involved nonsteady-state engine operation, a special truck version of the new and novel exhaust gas sampling system developed by the U. S. Public Health Service was employed. The original prototype sampling system, known as the PHS Variable Dilution Sampler, was described in an APCA paper[2]. Part of the preparations phase of the SwRI program involved the design, construction, and calibration of a truck version of the automotive system and was described in a special SwRI report[3].

Therefore, this is an interim report of the efforts under way at Southwest Research Institute for the Procedures and Emissions Background Development Section of the NCAPC, U. S. PHS, under Contract PH 86-67-72. The report covers the preparations and initial emissions results obtained from three vehicles prior to the acquisition of baseline data from a number of vehicles above 10,000 GVW. The initial emissions results obtained using a chassis dynamometer are compared with previously obtained emissions data for the same vehicles operated on the Detroit-Los Angeles road course. Once this relationship was established using the PHS Servo proportional sampler, experiments were conducted to relate the truck version of the PHS variable dilution sampler with the Servo proportional sampler. Chassis dynamometer cycles included the proposed 1970 constant speed cycle, as well as several experimental variable speed cycles based on actual operation of trucks over urban routes.

*Superscript numbers in parentheses refer to List of References at the end of this report.

II. OBJECTIVE

The overall objective of the current studies at Southwest Research Institute is to obtain baseline emissions data from gasoline powered trucks using experimental, "second generation" type procedures and the most advanced emissions sampling and analysis procedures available. To acquire the baseline emissions data required a substantial preparations phase involving further development of chassis dynamometer cycles, the design and construction of a truck version of the PHS Variable Dilution Sampler, and the establishment of correlation with previous program procedures and different exhaust sampling schemes.

This interim report is limited to a review and description of the preparations phase of the program. In addition to preparing a suitable variable dilution sampling system for use with heavy-duty trucks, reported in Reference 3, the preparations phase included two major objectives. The first objective was to establish the relationship between emissions obtained on the simplified SwRI chassis dynamometer and those previously obtained by Ethyl[1]. For this purpose, several vehicles previously investigated by Ethyl were obtained as well as the identical Servo proportional type sampling systems, flow balanced and calibrated carburetors, and distributors. The second objective of the preparations phase was to determine and establish the relationship of exhaust gas samples obtained by the variable dilution system and the Servo proportional system. The intent of this investigation was to permit acquisition of baseline data from a number of different types, sizes, and shapes of trucks above 10,000 GVW to be obtained, using the best sampling system for mass emissions measurement available.

III. SAMPLING AND ANALYSIS EQUIPMENT, INSTRUMENTS, AND PROCEDURES

Continuous sampling and analysis of vehicle exhaust using the NDIR analytical system has been well documented[4, 5, 6], and the PHS proportional sampling method has been described[7]. Information pertaining to the prototype PHS Variable Dilution Sampling System for use with automobile size engines is in the literature[4]. To obtain exhaust samples by this newer proportional technique with the larger truck powerplants required a redesign and repackaging of the prototype.

For clarity, it may be helpful to review both the continuous sampling and analysis and the proportional methods, and to describe in detail the truck version of the variable dilution system. All three methods were employed in this study to measure emissions.

A. Continuous Sampling and Analysis

This well-known method is specified in all current and proposed Federal standards for measurement of emissions from spark-ignited gasoline fueled vehicles. A typical system, as shown in Figure 1, consists of four, nondispersive, infrared NDIR gas analyzers to permit the rapid and continuous detection of 0 to 11% carbon monoxide (CO), 0 to 16% carbon dioxide (CO_2), and 0- to 1000- and 0- to 10,000-ppm hydrocarbon (HC) as normal (n) hexane (C_6H_{14}). Furthermore, the analysis system is designed to permit almost instantaneous readout via two dual-pen strip chart recorders by minimizing dead space and residence time. The advantages of this method include rapid and continuous monitoring throughout the test cycle to permit mode-by-mode analysis of raw undiluted exhaust. Measurement of oxides of nitrogen (NO_x), however, is difficult to accomplish with the continuous sampling and analysis system because of the lack of suitable, continuous, and fast responding NO_x instrumentation. NO_x means nitrogen dioxide (NO_2) plus nitric oxide (NO) expressed as ppm NO_2. Suitable NDIR instrumentation is available for NO measurement, but measurement of NO_2 involves oxidation of NO to its more stable state, NO_2. The principal oxide of nitrogen produced by piston engines, both gasoline and diesel fueled, is NO (over 90% under most conditions), and this product of combustion is unstable in the presence of oxygen (O_2). Another disadvantage, which is being overcome to an extent with the help of computers, is the data reduction required to integrate and weight exhaust emission concentrations. Also, it is not possible to determine engine air intake or exhaust flow rate when using the continuous sampling method.

B. PHS Servo Proportional Exhaust Sampling System

This development of the past several years has gained acceptance mainly in the test cycle development and field data acquisition of exhaust

FIGURE 1. CONTINUOUS SAMPLING AND ANALYSIS INSTRUMENTATION SYSTEM

emissions. The principle of operation permits collection of an integrated sample of raw engine exhaust incrementally proportional to the engine air throughput. By means of suitable transducers and servomechanisms, 0.1% of the exhaust emissions is continuously deposited into a small Tedlar* sample bag which was previously partially filled with a known amount of pure nitrogen diluent. This is determined by a laminar flow element measuring airflow and located at the inlet to the engine carburetor.

The vehicle or engine is then operated through the desired cycle and an exhaust sample is obtained. Shown in Figure 2 is a typical proportional sampler located adjacent to a vehicle under test. The laminar flow element is located inside the intake to the air cleaner, shown in Figure 3. This system has the advantage of being portable; it can be stowed inside a vehicle and operated to obtain exhaust samples over various road courses. Engine airflow, an important operating parameter, is measured by this system. Other advantages are simplicity of sample analysis and data reduction, and the inherently straightforward emissions calculations on a pound or gram per mile traveled basis. However, the system must be continuously calibrated and checked to assure reliable sampling and emissions results.

Predilution of the exhaust sample in 3 to 4 parts of pure nitrogen to "freeze" the exhaust constituents requires the availability of a suitable array of low-range NDIR instruments. Such an array is shown in Figure 4 and includes NDIR instruments to measure CO, CO_2, and HC as (n) Hexane and a flame ionization analyzer, FIA, for the measurement of total hydrocarbons. Not shown is a polarographic type O_2 instrument which is helpful in checking for possible air leaks in the sampling and exhaust transfer system. Not required, however, are the dual-pen strip chart recorders since only a single value, the overall bag-integrated concentration of the constituent, is of interest. The dilute exhaust analysis system, shown in Figure 4, was employed with both this proportional sampler as well as the variable dilution sampling system, which will be discussed next. Another feature of the diluted, integrated bag sample of exhaust via the proportional system, as well as the variable dilution system, is the simplicity in analysing for NO_x by means of the modified Saltzman syringe technique. Replicate syringe samples of the diluted exhaust may be quickly and simply obtained.

C. PHS Variable Dilution Sampling System

This system, a recent development of the National Center of Air Pollution Control, U. S. PHS, dilutes the entire vehicle exhaust with room air to produce a constant volume flow of exhaust plus diluent. The initial automotive prototype[4] was redesigned to handle the increased quantity of exhaust gases produced by truck engines. The resulting truck version of

*E. I. DuPont de Nemours and Co., Inc.

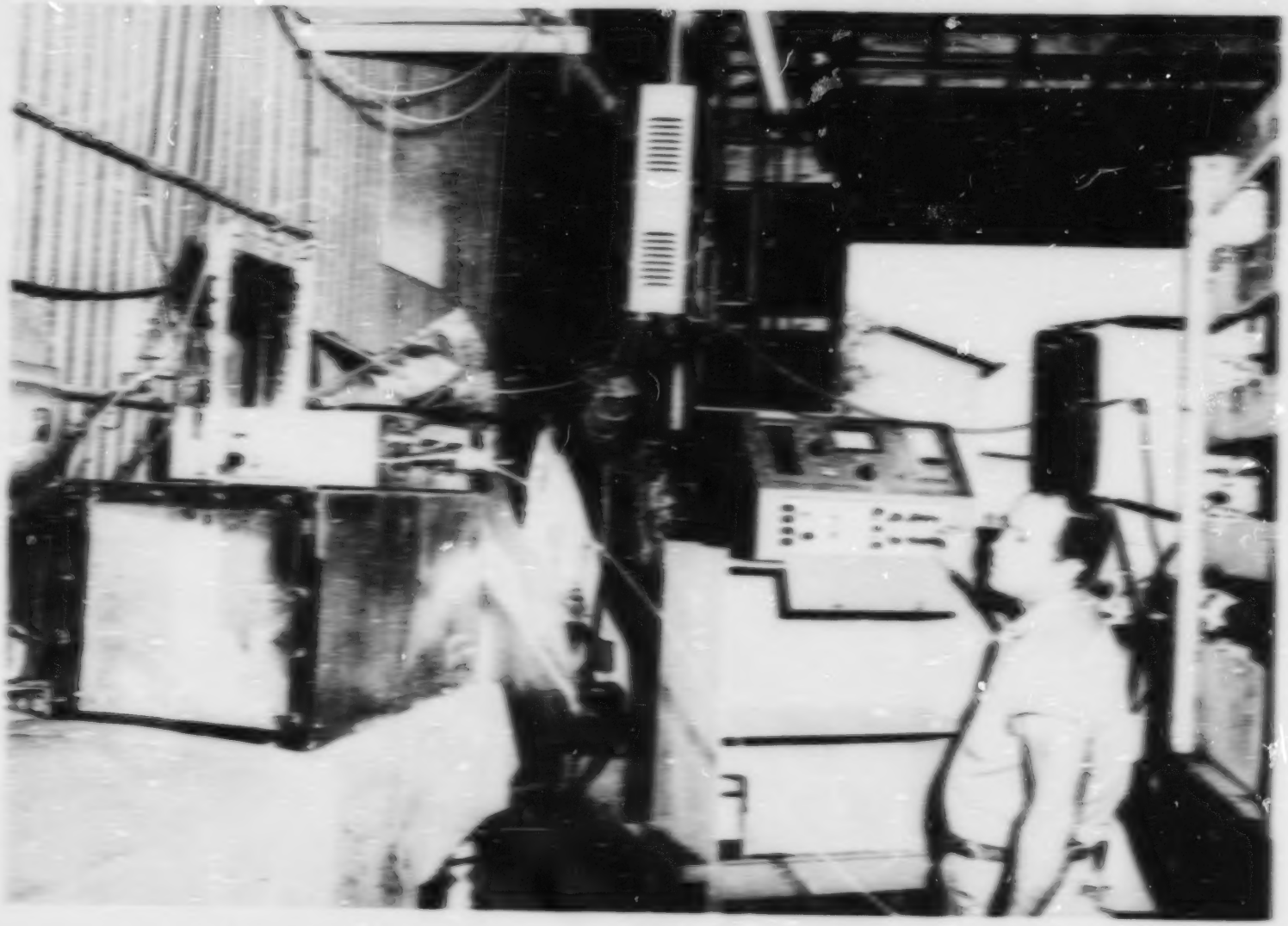

FIGURE 1. PHS PROPORTIONAL SAMPLING SYSTEM: BAC BOX SERVO AND OPERATION CONSOLE SHOWN

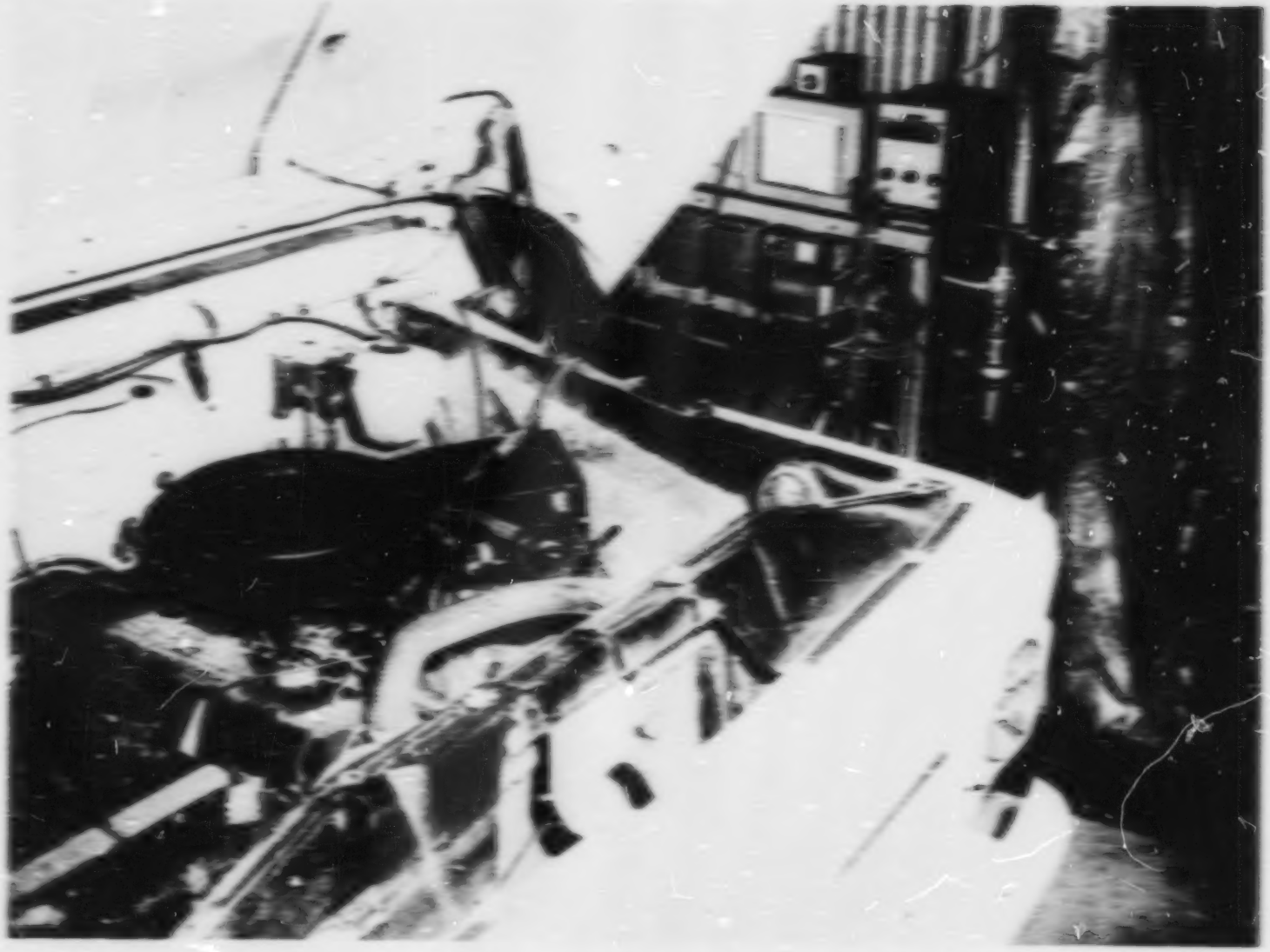

FIGURE 1. P45 PROPORTIONAL SAMPLING SYSTEM LAMINAR FLOW ELEMENT - TRANSDUCER INSTALLED

FIGURE 4. BAG SAMPLES OF VEHICLE EXHAUST ANALYZED BY FLAME IONIZATION AND NONDISPERSIVE INFRARED METHODS

the PHS variable dilution sampling system is shown schematically in Figure 5. The flow of the total vehicle exhaust is drawn through the inlet cone, along with a substantial quantity of room diluent air. Next, the diluted exhaust travels through the tubes of a "U"-shaped, air to exhaust, sheet and tube type, stainless steel heat exchanger. Just before the cooled diluted exhaust reaches the large, rotary, positive displacement pump, a small constant flow of the mixture is removed by an isokinetic probe and a small, positive displacement pump. This split sample of diluted exhaust is then deposited into a 4-ft-wide by 9-ft-high Tedlar* plastic bag. Once the test cycle is complete, a small portion of the mixture of exhaust and diluent is transferred from the system bag, as with the servocontrolled proportional sampler, and analyzed with the previously discussed NDIR-FIA system (Figure 4). A unique feature of the truck version is the two-speed system blower motor to permit operation on large trucks and medium size vehicles. Flow rates of 625 and 950 SCFM are approximately double and triple the flow capacity of the automotive prototype. Those portions of the sampling system in contact with the exhaust were fabricated from stainless steel and Teflon*. The interior of the small pump, used to withdraw the diluted sample for deposit into the system bag, was nickel plated. A number of accessories for monitoring system temperatures, pressures and system blower and sample pump speeds were also provided. The results of a complete calibration and shakedown of this redesigned, repackaged system were presented in a special report[3].

Figures 6, 7, and 8 are various views of the truck version of the variable dilution sampling system prepared for use in this program. From Figure 6, the front view, the heat exchanger and cooling fan may be seen at the top. At left is the 6-in.-diameter stainless flexible exhaust sampling pipe which enters the lower half of the heat exchanger. Also shown in this view is the system blower and its two-speed direct motor drive. Above this assembly are the electrical controls, motor starters, etc. To the right of the cooling fan is the strip chart temperature recorder provided to monitor the various system temperatures. Many of these same items are shown in Figure 7, a rear view that indicates the flow through the heat exchanger. Figure 8 shows a close-in view of the sample pump, the sample flow controls, and system bag. Although not shown, the isokinetic sample probe is located and directed upstream in the center of the inlet pipe to the system blower. An additional feature of this system is a provision for continuous sampling of the dilute mixture as the operating cycle progresses.

It is important to obtain the vehicle exhaust so as not to influence the engine operation by inducing a partial pressure in the exhaust system different from that normally experienced. This criterion was met by the addition of a cone shown in Figure 9 at the intake of the variable dilution sampler.

*E. I. DuPont de Nemours and Co., Inc.

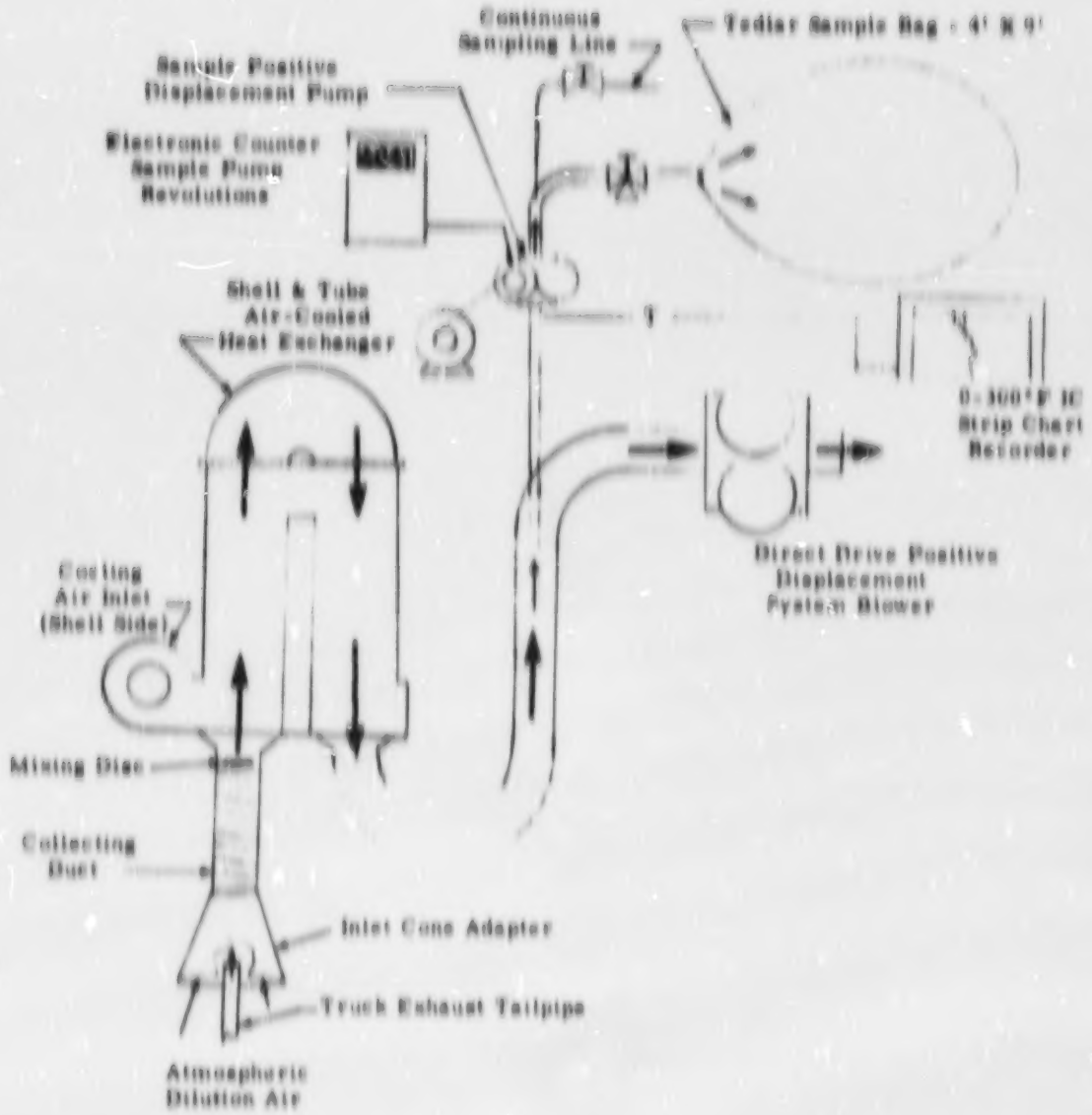

FIGURE 5. VARIABLE DILUTION SAMPLING SYSTEM SCHEMATIC

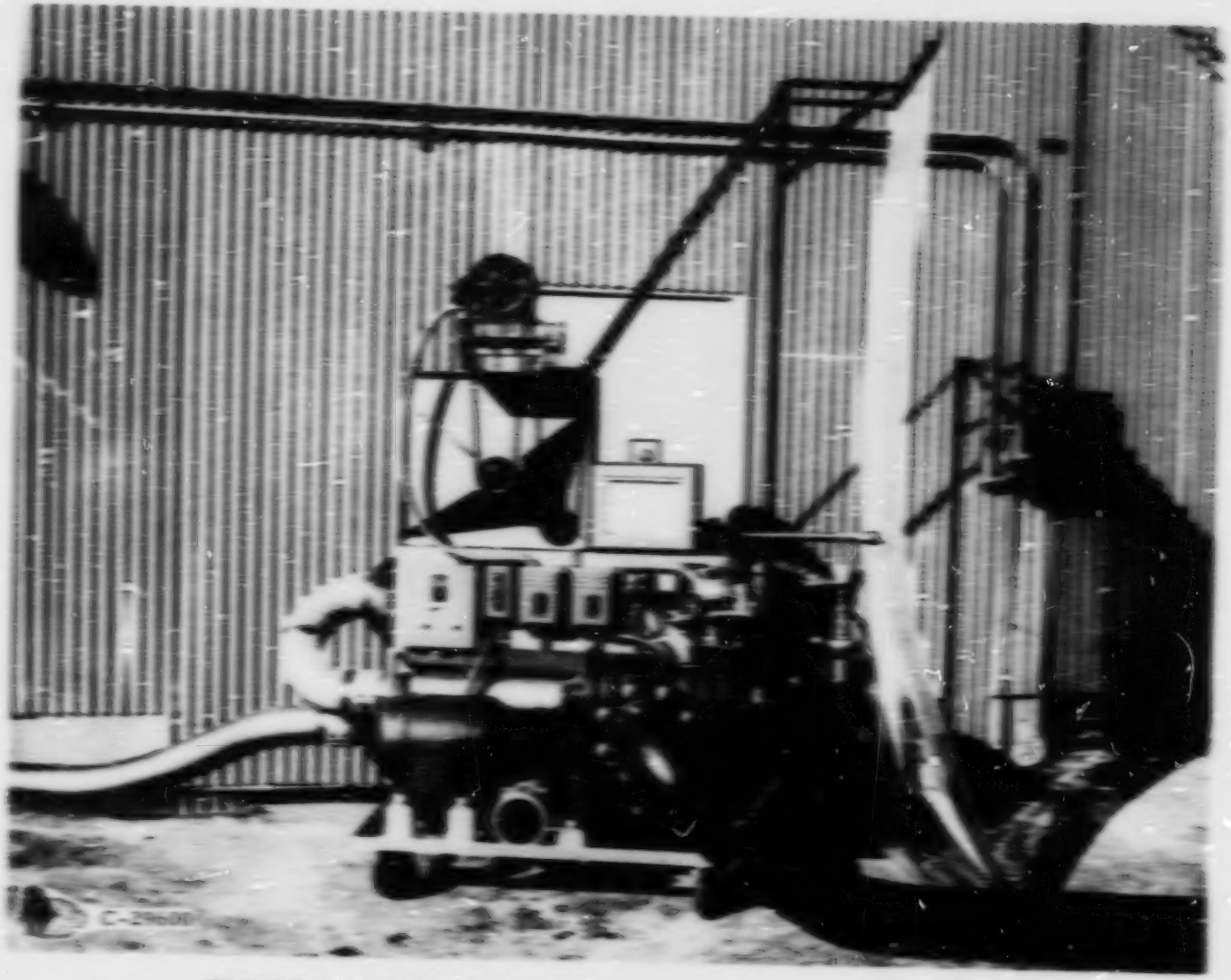

FIGURE 6. VARIABLE DILUTION SAMPLER - FRONT VIEW

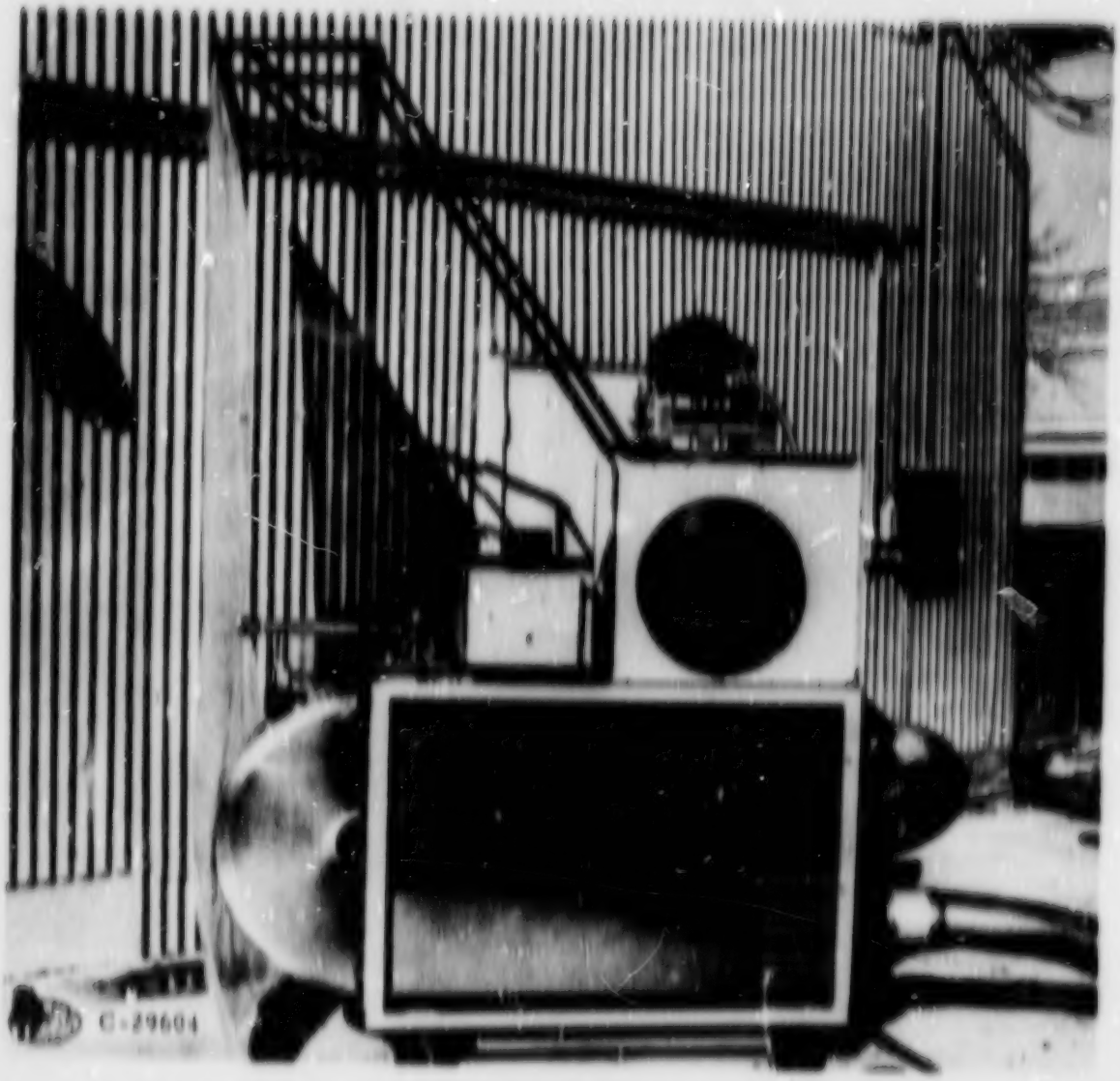

FIGURE 7. VARIABLE DILUTION SAMPLER - REAR VIEW

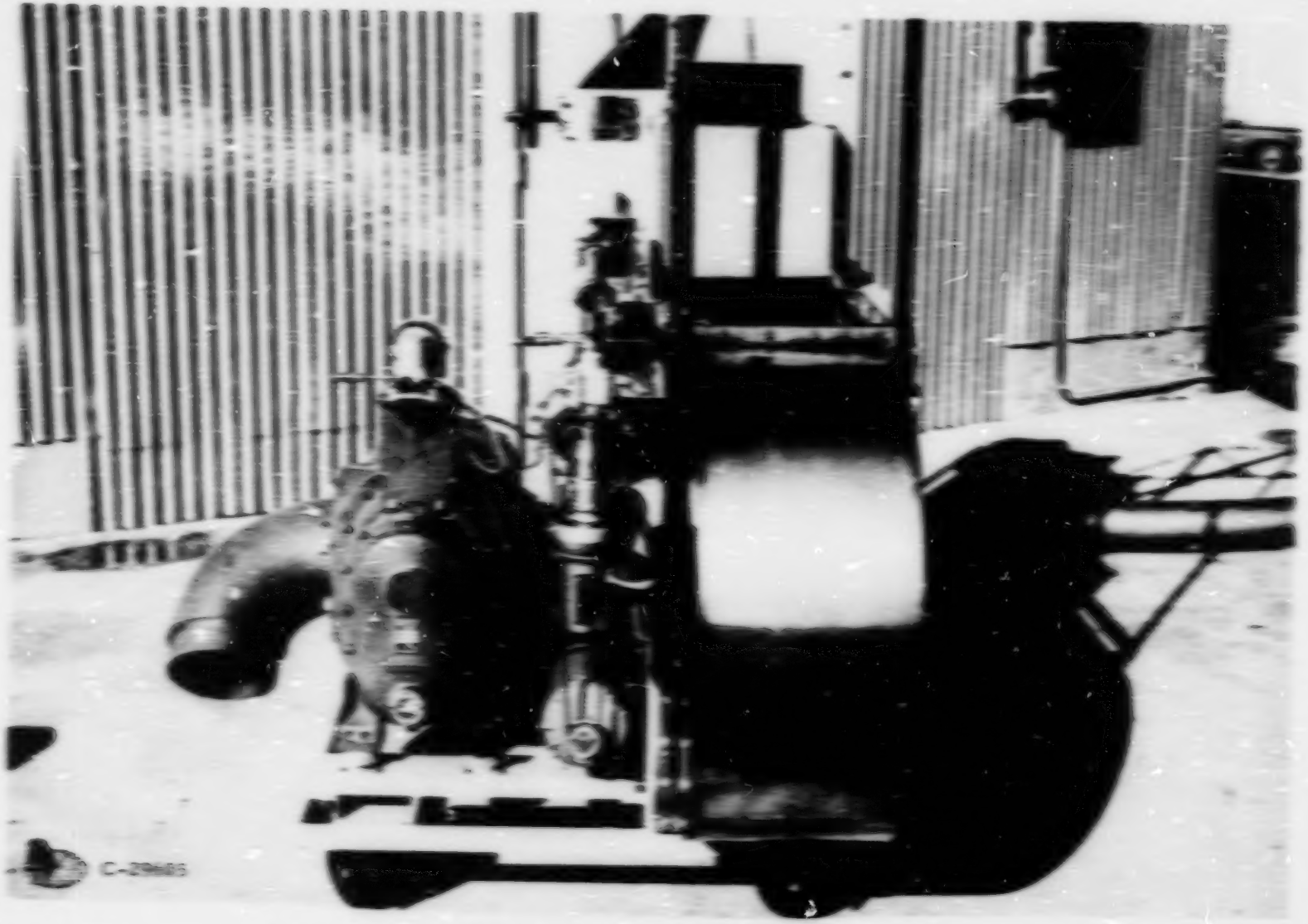

FIGURE 6. VARIABLE DILUTION SAMPLER - RIGHT END VIEW

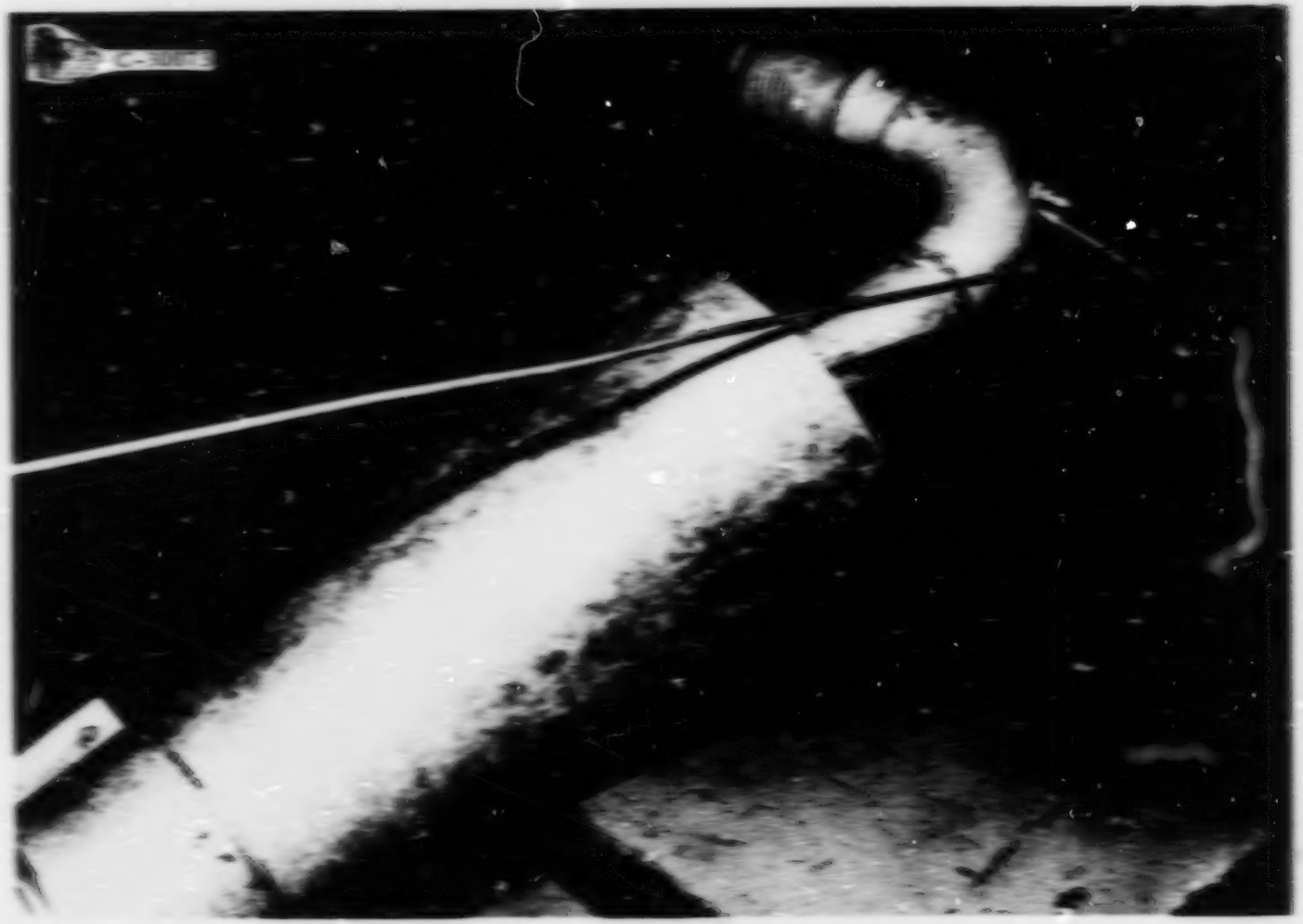

FIGURE 9. EXHAUST INLET CONE FOR USE WITH TRUCK VERSION PHS VARIABLE DILUTION SAMPLER

Note also the entrance of the two probes for the proportional servosampler and the continuous sampler. This arrangement was used when sampling simultaneously.

The variable dilution proportional technique possesses some outstanding advantages: simplicity, ease of application (no requirement to prepare the vehicle for test), reliability, and dependability. As with the servocontrolled proportional sampling system, the integrated bag sample of exhaust results in a single set of CO, CO_2, HC and NO_x readings and permits simple, straightforward computation of mass emissions. With this system, the exhaust is diluted with room air as it is collected, and precharging the sample bag with nitrogen is not required. However, the FIA instrument must be spanned with air diluted hydrocarbon standards instead of the normal nitrogen diluted gases. This compensates for the O_2 response of the FIA instrument. In addition, the effect of the diluent air contaminants or background of hydrocarbons, CO, and NO_x must be taken into consideration.

Shown in Figure 10 is a typical, gasoline powered truck prepared for simultaneous sampling by the proportional and variable dilution systems. Note the large sample holding bag to the right of the variable dilution machine and the proportional system console near the operator. The servosystem and bag box for the proportional method are shown in the background. Operation of the vehicle according to specified driving cycles, as well as operation of both sampling systems, was performed by a single laboratory technician. All operation was managed from the driver's seat of the vehicle as shown.

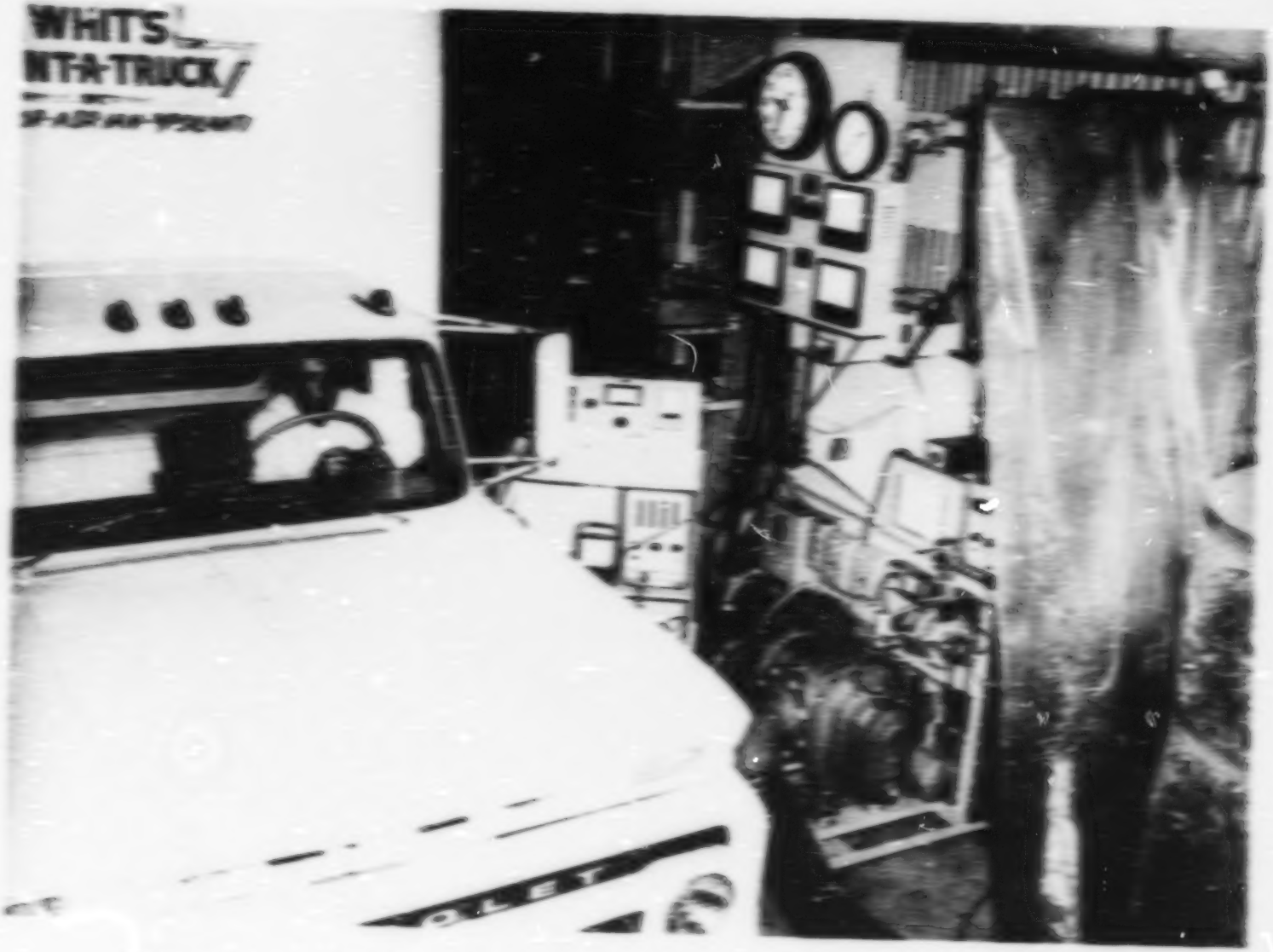

FIGURE 10. TYPICAL GASOLINE POWERED TRUCK PREPARED FOR EMISSIONS SAMPLING BY PHS PROPORTIONAL AND VARIABLE DILUTION METHODS

IV. VEHICLE OPERATING PROCEDURES

Before discussing emissions results obtained with the sampling and analysis techniques previously described, it may be helpful to list the vehicle operating cycles and procedures investigated. With the exception of the proposed 1970 heavy truck cycle, the chassis dynamometer cycles employed were experimental in nature.

A. Proposed 1970 Federal Heavy-Duty Gasoline Truck Dynamometer Cycle

This cycle, known as the "constant speed" cycle, employs nine modes, shown in Table I, in which the engine speed remains essentially constant for sequences 2 through 9.

Constant speed is obtained by operating the engine, or complete vehicle, on a laboratory or chassis dynamometer of the all-electric type. By either power absorbing or motoring, the engine speed is maintained while changing the value of intake manifold vacuum. For example, the 19-in. Hg vacuum setting, sequence 5, is a part throttle deceleration which requires dynamometer motoring. In operation, this cycle is repeated four times with an idle mode prior to the first cycle and after the fourth cycle. This constant speed-type cycle was simulated by the SwRI chassis dynamometer system to obtain representative emissions data for two of the correlation trucks.

B. Experimental Truck Dynamometer Cycles

The ability of the SwRI vehicle road simulation facility[8] to reproduce realistic field operation of heavy-duty vehicles was the major factor in establishing this baseline data program. Briefly, the SwRI system includes large, solid disc flywheels directly connected to a widely used type of water brake tandem-axle chassis dynamometer. The system is capable of simulating the inertia of 16,000- and 25,000-lb vehicles with a single-drive axle or 32,000- or 41,000-lb vehicles with tandem-drive axles. Up to 200 hp may be absorbed per axle by the water brake dynamometer. The characteristic of this type of unit is to follow the "q" load curve, i.e., closely simulate the operation of a vehicle where load increases exponentially with increasing vehicle forward speed. This simple yet realistic type of road simulation was achieved in the laboratory. The two basic experimental cycles described below were essentially the same as are proposed in Reference 1. Primarily, the modifications involved acceleration through transmission gears under repeatable, wide open throttle (WOT) conditions with normal-habit gear shifting. The Class III, nine-mode experimental cycle is presented in Table 2. This cycle may be run at level road load or at a higher cruise power condition, merely by presetting the water brake

TABLE 1. PROPOSED 1979 TEST PROCEDURE HEAVY-DUTY VEHICLES DYNAMOMETER OPERATION CYCLE

Sequence	Mode	Manifold Vacuum, in. Hg	Time in Mode, sec	Cumulative Time, sec
1	Idle		70	70
2	Cruise	16	23	93
3	PTA	10	44	137
4	Cruise	16	23	160
5	PTD	19	17	177
6	Cruise	16	23	200
7	PT	3	34	234
8	Cruise	16	23	257
9	CT		43	300

Engine dynamometer speed 2000 ± 100 rpm
Chassis dynamometer vehicle speed 35 ± 2 to 40 ± 2 mph to give engine speed close to 2000 rpm.

Note: An initial 5-min idle, two warmup cycles, and two hot cycles constitute a complete dynamometer run.

TABLE 4. EXPERIMENTAL CLASS III GASOLINE TRUCK CHASSIS DYNAMOMETER CYCLE

Sequence	Mode	Gear	Vehicle Speed, mph	Time, sec	
				Duration	Cumulative
1	Idle	N	0	20*	20*
2	Acceleration (WOT†)	2	0-15		
3	Acceleration (WOT†)	3	15-24		
4	Acceleration (WOT†)	4	24-35	30	50
5	Deceleration (CT†) (With brakes if necessary)	4	35-25	10	60
6	Cruise (Vacuum to be investigated)	4	25	12	72*
7	Acceleration (PT†)	4	25-28	6*	78*
8	Cruise (Vacuum to be investigated)	4	28	12*	90*
9	Deceleration (CT, declutch at 16 sec, then apply brakes to return to 0 mph for start of next cycle)	4	28-0	16*	106*

Repeat above for total of four cycles, total time of 424 sec or 7.06 min.

*Time must be adhered to.
†WOT is wide open throttle; PT is part throttle; CT is closed throttle.

dynamometer at an arbitrary vehicle speed such as 30 mph to reflect road manifold depressions obtained under level road or uphill conditions. This is also true of the twelve-mode experimental Class IV cycle shown in Table 1. Similar to the Class III cycle, the Class IV experimental procedure can be operated at a variety of cruise power conditions. The results for both experimental cycles will be presented for several road load conditions with the vehicle loaded with 0.5 payload to simulate real vehicle operation. Additionally, the results, which will be discussed later, were obtained using inertia simulation equivalent to 16,000 lb of vehicle mass. Only Indolene motor fuel, which conforms to Federal procedures[6], was employed during the emissions tests.

TABLE 1. EXPERIMENTAL CLASS IV GASOLINE TRUCK CHASSIS DYNAMOMETER CYCLE

Sequence	Mode	Gear	Vehicle Speed, mph	Time, sec	
				Duration	Cumulative
1	Idle	N	0	27*	27*
2	Acceleration (WOT†)	2	0-11		
3	Acceleration (WOT†)	3	11-20		
4	Acceleration (WOT†)	4	20-31		
5	Acceleration (WOT†)	5	31-35	39	66
6	Deceleration (CT†) (With brakes if necessary)	5	35-21	13	79
7	Cruise (Vacuum to be investigated)	5	21	28	107*
8	Acceleration (PT†)	5	21-24	19*	126*
9	Cruise (Vacuum to be investigated)	5	24	28*	154*
10	Deceleration	5	24-21	6*	160*
11	Cruise (Vacuum to be investigated)	5	21	28*	188*
12	Deceleration (CT, declutch at 12 sec and then apply brakes to return to 0 mph for start of next cycle)	5	21-0	12*	200*

Repeat above for total of two cycles, total time of 400 sec or 6.67 min.

*Time must be adhered to.
†WOT is wide open throttle; PT is part throttle; CT is closed throttle.

V. EMISSIONS RESULTS

Discussed in this section are the results of several series of experiments conducted to determine the level of correlation between current SwRI and previous Ethyl work. For purposes of this correlation, the SwRI chassis dynamometer results, using experimental cycles, are compared to the Detroit-Los Angeles (DLA) road course data[1] gained with the same vehicle and servoproportional sampling equipment used by Ethyl. Once this correlation was determined, the experimental cycles were used to investigate the extent of correlation between the servoproportional sampler and the truck version of the variable dilution sampler, the next objective. These two samplers, operated simultaneously, were employed during experiments involving several different road load conditions.

Once the two major objectives of this preparations phase were complete, a series of runs was made using the proposed 1970 Federal Standard Heavy-Duty Truck Cycle. Although both the continuous and variable dilution samplers were employed, comparisons are discussed with previous Ethyl results for the continuous sampling and analysis. This comparison of the emissions from the experimental cycles at various load conditions to those obtained with the Federal constant speed cycle is also included.

In each of the three discussion areas of this section, the single Class III truck results are presented first, followed by the two Class IV trucks. The data summarized in the tables of this section are usually the average of a test series involving four identical runs. The run results are included in Appendices A and B, and provide supporting data as well as an indication of run-to-run repeatability and variability. Appendix A contains emissions data obtained with the Class III truck. The results with the two Class IV vehicles are included as separate sections of Appendix B for the 1966 and 1967 stake trucks.

The results are presented in tabular form and in order of their discussion in the text. Both Classes III and IV, Appendix A and B, results follow the chronological order of: first, operation with experimental cycles using the servoproportional sampler for comparison to previous work; second, correlation of variable dilution results with servoproportional under the same conditions; third, continuous and variable dilution sampling and analysis results with the proposed 1970 Federal Standard Heavy-Duty Truck Cycle.

A. Correlation of Experimental Cycle Results with DLA Road Course Data

The Class III vehicle selected for the initial familiarization and cycle emissions correlation with previously sponsored PHS work was a 1965

Chevrolet C60 van, single-axle truck with 292-cu in., six-cylinder engine, four-speed transmission, single-speed 7.40:1 rear axle ratio, 8.25 × 20 tires, with a gross vehicle weight of 19,500 lb and tare weight of 8310 lb. This vehicle was used in previous gasoline truck road course and chassis dynamometer investigations, and, according to the rental agency, no engine or driveline maintenance had been performed between the time the truck was originally investigated and the time it was obtained by SwRI. To facilitate the correlation with Ethyl road course results, the same servo-proportional sample with large sample bag box, flow-balanced carburetor, and calibrated distributor, originally used with the Class III Chevrolet van, was employed. The system was shown previously in Figures 2 and 3.

As described in the SwRI Special Status Report of August 23, 1967[9], difficulties were encountered in repeating the Ethyl chassis dynamometer cycle on the simplified SwRI CTFF-200-200 water brake chassis dynamometer with a 16,000-lb inertia simulation. Operation of the truck was particularly difficult during the initial acceleration modes of the Class III cycle. By slightly changing the time allocations during acceleration in 2nd, 3rd, 4th, and 5th gears, adopting normal driver habit gear shifting, and changing all partial throttle settings to wide open throttle, the total acceleration time specified through the gears for the Class III median truck was obtained.

On the advice of PHS Technical Officer, correlation emission data were obtained with the modified Class III chassis dynamometer cycle designated the experimental nine-mode cycle and described in Table 2. With the servoproportional sampler connected to the Chevrolet van, emission data were taken with three preset load conditions; road load as established by the manifold vacuum on level road at 30 mph with the vehicle loaded with one-half payload, slight uphill load (road load plus 12 hp), and uphill load (road load plus 24 hp). These various preset vehicle dynamometer load conditions were used to obtain exhaust emissions for comparison to the PHS provided Ethyl DLA road course and chassis dynamometer data.

A summary of the average SwRI and PHS furnished data[1] for the Class III Chevrolet van is presented in Table 4. Hydrocarbon emission results are listed as analyzed by NDIR and FIA on a pounds of carbon per mile driven or mass basis. Similarly, NO_x as pounds of NO_2 per mile, CO as pounds of CO per mile, and CO_2 as pounds of CO_2 per mile are listed. Two operating parameters of interest, average air/fuel ratio and engine exhaust flow rate in standard cubic feet (SCF) per mile are shown. The NDIR unburned hydrocarbon values characteristically are less than the FIA results such that the FIA to NDIR ratio is an average of 1.8.

Listed first is the road course DLA results, followed by the chassis dynamometer data taken from Reference 1. As used in Reference 1, the degree of correlation between the chassis dynamometer and DLA road results is indicated by a comparison ratio. If the chassis dynamometer

TABLE 4. COMPARISON OF NINE-MODE EXPERIMENTAL CYCLE AT VARIOUS LOAD CONDITIONS TO ROAD COURSE EMISSIONS

Vehicle: 1965 Chevrolet Van
Engine: 272-cu in., six-cylinder

Sampler: Servoproportional
Fuel: Indolene

Cycle	Load Condition	Data Source	HC/TB, lb/mi	HC/FTA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel Avg	Exhaust Flow, SCF/mi
DLA	Road	PBS	0.0322	0.0571	0.0188	0.441	1.795	12.65	131.0
Ch. Dyn.		PBS	0.0297	0.0513	0.0285	0.417	1.956	12.76	142.5
	Comparisons Ratio		0.92	0.90	1.52	0.95	1.09	1.01	1.09
Ch. Dyn.*	Road (10 hp)	SwRI	0.0269	0.0455	0.0177	0.395	1.792	12.90	136.0
	Comparisons Ratio		0.84	0.80	0.94	0.90	1.00	1.02	1.04
Ch. Dyn.*	Slight Uphill (30 hp)	SwRI	0.0257	0.0457	0.0280	0.424	2.06	12.75	155.5
	Comparisons Ratio		0.80	0.80	1.48	0.96	1.15	1.01	1.19
Ch. Dyn.*	Uphill (42 hp)	SwRI	0.0277	0.0506	0.0243	0.447	2.40	12.63	183.0
	Comparisons Ratio		0.86	0.88	1.29	1.46	1.34	1.00	1.44

*Supporting four-run data presented in Table I of Appendix A.

data are the same as the road data, a value of 1.0 would be obtained. The magnitude of the ratio indicates the direction and degree to which the chassis dynamometer data deviate from the road data. Values less than one mean that the dynamometer data are low relative to the road, and values greater than one mean that the chassis data are high relative to the road. This simple numerical analysis provides a uniform basis for comparing chassis dynamometer laboratory results with the DLA road data.

Next, the SwRI chassis dynamometer results are presented for three load conditions of level road (18 hp), slight uphill (30 hp), and uphill (42 hp). Comparison ratios are listed below each mass emission value to indicate the degree of agreement with the DLA road course.

In general, there is good agreement between the level road experimental cycle data (SwRI) and the DLA road course data. The comparison ratio ranges from a minimum of 0.80 to a maximum of 1.04, with an overall seven-variable average of 0.95. However, the HC, CO, and NO_x data--with comparison ratios less than one--indicate that this particular Class III truck did not produce as much HC, CO, and NO_x under the experimental cycle as on that reported on the DLA course. Airflow through the engine was slightly greater than the road airflow. One way of considering the SwRI road load results is that the HC, CO, and A/F comparison ratios reveal the overall cycle emissions to be slightly lower relative to the DLA data.

In an attempt to bring the HC and CO into closer agreement with the DLA road data, two higher load conditions were arbitrarily selected representing a vehicle operating under a slight uphill and an uphill condition. By operating at a slight uphill condition, 30 hp preset into the water brake dynamometer at 30 mph and retained, no change in HC was obtained, although NO_x and CO were increased, particularly NO_x with a comparison ratio of 1.48 instead of 0.94 at level road load. A wider spread of emission comparison ratios did appear with a maximum of 1.48 and a minimum of 0.80, although the overall average of 1.06 does indicate a good comparison. The comparison ratios of less than one for the HC and CO data and the greater than one values of NO_x and A/F indicated that operation at the slight uphill condition may still be considered lean relative to the road results.

Further investigation of the effect of load on emissions involved an uphill (road load plus 24 hp) condition. The emission ratio comparison showed all emissions except HC to be in excess of the road data with the overall average comparison ratio of 1.18, with a maximum of 1.46 and a minimum of 0.86. However, the road operation air/fuel ratio was equaled, and the increase to an apparent overall richer operation from the level road load was signaled by the increase in HC, CO, and A/F data and the decrease in the NO_x emissions.

Considering the nine-mode PHS (Ethyl) cycle Chevrolet van data from Reference 1 and listed on Table 4, the HC and CO data with ratios less than one and the NO_x and A/F data with ratios greater than one suggest that the cycle may also have been run at a leaner condition than the road. Although not explainable, the HC and CO emission data were maintained at a higher level of correlation to the road results than the SwRI HC and CO at essentially the same A/F ratio and airflow through the engine.

The initial Class IV vehicle selected for use in the familiarization and cycle emissions studies for correlation with previous PHS sponsored work was a 1966 International Harvester Model LS 1700 stake body truck. The single-axle gasoline truck was powered by an IH 345-cu in. V-8 engine through a five-speed transmission and single-speed, 6.50:1 rear axle equipped with 9.00-20 tires. The GVW of the truck is 34,000 lb, with a tare weight of 9030 lb. Selection of this truck was made because of its availability from the rental agency. No engine or driveline maintenance had been required since the previously sponsored investigation. As with the Class III correlation truck, difficulties were encountered in attempting to operate the Class IV twelve-mode cycle developed by Ethyl on the simplified SwRI road simulation facility. These difficulties were described in Reference 9 and basically resulted due to the inability of this particular 1966 IHC truck to accelerate against the 16,000-lb equivalent vehicle inertia within the times specified in Reference 1. With the advice of the PHS Technical Officer, modes 2 and 5, the accelerations in 2nd and 5th gears, were increased to full throttle setting and, as with the Class III vehicle, normal driver gear shifting habit employed. The resulting cycle, described on Table 1 as a twelve-mode experimental cycle, was employed to obtain emissions from the IHC and the other Class IV stake truck studied. As described in the special status report, Reference 9, the IHC stake operated the experimental Class IV twelve-mode cycle under heavier cruise vacuums than expected by the previously reported road results. This particular vehicle was judged underpowered by Ethyl for a Class IV vehicle, and this may have been the reason for the cruise vacuum differences found.

Shown on Table 5 are the DLA road and chassis dynamometer results reported in Reference 1 and the chassis dynamometer results obtained using the simplified SwRI road simulation facility. As in Table 4, the original data provided by PHS from Reference 1 are listed first for the DLA road and then the chassis dynamometer. The reported comparison ratios range from a maximum of 2.05 for NO_x emissions to a minimum of 0.52 for CO emissions with an overall average of 1.22. The overall set of emissions data was adjudged to lack the desired degree of correlation with the road course. The main reason given in Reference 1 was that the vehicle was underpowered.

Next, the data acquired with the experimental twelve-mode cycle are tabulated for a level road load condition. In general, there is excellent

TABLE 5. COMPARISON OF TWELVE-MODE EXPERIMENTAL CYCLE AT VARIOUS LOAD CONDITIONS TO ROAD COURSE EMISSIONS

Vehicle: 1966 IEC Sedan
Engine: 345-cu in. V-8

Sampler: Servoproportional
Fuel: Indolene

Cycle	Load Condition	Data Source	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel Avg	Exhaust Flow, SCF/mi
DLA	Road	PBS	0.0261	0.0483	0.0158	0.325	1.74	12.88	128.5
Ch. Dyn.		PBS	0.0229	0.0430	0.0525	0.266	2.86	13.37	163.5
	Comparison Ratio		0.88	0.89	2.05	0.82	1.65	1.04	1.26
Ch. Dyn.*	Road (14 hp)	SwRI	0.0236	0.0489	0.0127	0.421	2.11	12.79	142.7
	Comparison Ratio		0.91	1.01	0.805	1.29	1.21	0.99	1.11
Ch. Dyn.*	Slight Uphill† (14 hp)	SwRI	0.0236	0.0469	0.0122	0.450	2.19	13.00	160.0
	Comparison Ratio		0.91	0.97	0.775	1.38	1.26	1.01	1.24

*Supporting four-run data presented in Table 1 of Appendix B.
†This set of run data was forwarded to PBS in a preliminary rough pencilled table dated September 14, 1967, as road load data. The original misinterpretation was discovered by the high engine airflow rate, and recheck of original data confirmed the error.

agreement with the road data as exemplified by the comparison ratio maximum of 1.29 for CO emissions and the minimum of 0.805 for the NO_x emissions, with an overall average of 1.04. The exhaust airflow rate during this cycle is at a more acceptable ratio of 1.11 as opposed to the ratio of 1.26 computed for the Ethyl data.

The last set of emissions presented on Table 5 was with the experimental twelve-mode cycle with a slightly higher than level road load preset in the water brake. At this slight uphill condition, a good correlation also is indicated by the overall average comparison ratio of 1.08. The increase in loading with the experimental cycle is readily indicated by the increase in airflow rate and carbon dioxide content. The increase in CO suggests a richer operating condition with an increase in load. The increase in A/F ratio and the essentially unchanged HC concentration, however, do not confirm this trend.

In order to investigate further the level of correlation with previous data in the Class IV weight range, a 1967 Chevrolet C60H stake truck powered by a 1966, 366-cu in. V-8 engine through a five-speed Clark transmission and an Eaton two-speed differential, was obtained from General Motors Research. This particular truck engine was used previously in a 1966 truck chassis to gain emissions data under PHS contract work and the results reported in Reference 1.

Although the engine was installed in a different chassis and drive train between tests at SwRI and previous PHS sponsored work, a good correlation was found as shown on Table 6. As in Tables 4 and 5, the original DLA road course data are presented first followed by results reported in Reference 1 for this vehicle operated under the Ethyl dynamometer procedure. A review of the comparison ratios listed below the Ethyl chassis dynamometer results indicates excellent agreement with the DLA data. Only the minimum ratio of 0.89 for the CO concentration can be pointed out as low relative to the road data.

As reported in the January 5, 1968, SwRI progress report[10], this particular stake truck evaluated at SwRI was loaded with one-half payload calculated on the basis of 30,000 GVW and 7990-lb empty weight to establish a level road power condition equivalent to that previously used. These level road load data with foregoing modifications to the Class IV mode cycle are tabulated next on Table 6. The HC and A/F results are the only data that satisfactorily correlate with the DLA road course data. The NO_x, CO, CO_2, and exhaust flow appear to be at about one-third the concentration of the corresponding road data indicating a need for more load during the cycle. This trend was not indicated with the first Class IV truck. As a result of this apparent lack of overall correlation, a study was made to determine the effect of load and consequent correlation with the road course data. A number of road load conditions were included and are listed by

TABLE 6. COMPARISON OF TWELVE-MODE EXPERIMENTAL CYCLE AT VARIOUS LOAD CONDITIONS TO ROAD COURSE EMISSIONS

Vehicle: 1967 Chevrolet Stake
Engine: 396-cu in. V-8

Sampler: Servoproportional
Fuel: Indolene

Cycle	Load Condition	Data Source	HC/CL, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel Avg	Exhaust Flow, SCF/mi
ILA	Road	PHS	0.0147	0.0368	0.0488	0.2810	1.026	13.96	197.5
Ch. Dyn.		PHS	0.0238	0.0374	0.0446	0.1788	2.783	15.73	186.1
	Comparison Ratio		1.62	1.015	0.93	0.69	0.92	0.985	0.94
Ch. Dyn.*	Road (12 hp)	SwRI	0.0196	0.0348	0.0252	0.1340	2.115	15.68	147.5
	Comparison Ratio		0.965	0.965	0.525	0.69	0.78	0.98	0.75
Ch. Dyn.*	Slight Uphill (22 hp)	SwRI	0.0189	0.0333	0.0306	0.162	2.225	13.64	156.5
	Comparison Ratio		0.96	0.905	0.64	0.81	0.735	0.98	0.79
Ch. Dyn.*	Moderate Uphill (34 hp)	SwRI	0.0174	0.0315	0.0345	0.193	2.39	13.61	171.0
	Comparison Ratio		0.88	0.86	0.76	0.96	0.79	0.98	0.80
Ch. Dyn.*	Uphill (44 hp)	SwRI	0.0172	0.0324	0.0441	0.218	2.66	13.61	193.3
	Comparison Ratio		0.875	0.88	0.92	1.085	0.87	0.98	0.98

*Supporting four-run data presented in Table 7 of Appendix B.

increasing power setting from the level road load of 14 hp to an uphill condition of 44 hp with intermediate settings at 22 hp (slight uphill) and 34 hp (moderate uphill). All of these power settings were preset in the water brake dynamometer at 30 mph and retained during the cycle operation. From the four road power conditions listed, the uphill load condition results listed at the bottom of Table 6 correlated the best with the DLA road data. The increase in loading was evidenced by an increase in exhaust airflow, the air/fuel ratio decreased (fuel rich) and the CO increased. The increase in NO_x and the decrease in unburned hydrocarbons concentration suggest improved combustion at the heavier loading.

In brief, correlation with the road course (DLA) was established at an uphill road condition for the 1967 Chevrolet stake truck. This was not the case for the other Class IV truck where the correlation was established at a level road condition. Since the same closed road course was used to obtain the DLA data for both Class IV trucks, the uphill load condition correlation with road course data does show a different trend. The SwRI data bear out the increase in loading from level road to an uphill condition via the steady increase in exhaust flow. One possible explanation for the lack of correlation at level road load with the 1967 Chevrolet stake truck might be possible changes in adjustment or other engine modifications in carburetion and ignition between the time the original measurements were made and the vehicle was obtained for use in the SwRI program.

In summary of this section, satisfactory correlation was demonstrated between the DLA road course results and the experimental cycle data via the simplified SwRI chassis dynamometer for the single Class III vehicle and the Class IV 1966 IHC stake truck at level road load power settings. The other Class IV vehicle correlated well with the previously obtained road data under an uphill road load power setting. As a result of these investigations, it was found that the Class III and Class IV chassis dynamometer cycles reported in Reference 1 could be employed in the simplified SwRI road simulation system with modifications. Using these adapted experimental cycles, a satisfactory level of agreement and correlation to that reported in Reference 1 was obtained.

B. Correlation of Variable Dilution with Servoproportional Sampler Results

With the successful correlation of the experimental cycle results with the DLA road course data, the next step was to establish the correlation between the variable dilution sampler and the servoproportional system used exclusively to this point. The emissions results, obtained simultaneously by both types of sampling systems, will be analyzed by the comparison ratio technique. These results are tabulated in summary form on Table 7 and indicate the maximum, minimum, and average based on a minimum of four replicate runs. The vehicle was operated on the nine-mode

TABLE 7. CLASS III GASOLINE POWERED TRUCK TWELVE-MODE EXPERIMENTAL CYCLE EMISSIONS[a]

Vehicle: 1965 Ven., 19,500-lb GVW
Engine: 292-cu in., six-cylinder

Fuel: Indolene
Cycle: See Table 2

Run Condition	Vehicle Power abs, hp	Proportional Sampling Method		NDIR CO&HC, lb/mi	FIA CO&HC, lb/mi	NO_{2p}, lb/mi	CO, lb/mi	CO_{2p}, lb/mi	Air/ Fuel Avg.	Exhaust Flow, SCF/mi
Level Road Load	10	Servo	Max	0.0264	0.0498	0.0244	0.384	1.830	12.98	174.0
			Min	0.0240	0.0396	0.0213	0.334	1.700	12.85	134.7
			Avg	0.0255	0.0469	0.0227	0.362	1.768	12.91	135.8
		Variable Dilution	Max	0.0312	0.0554	0.0255	0.472	1.815		
			Min	0.0267	0.0469	0.0232	0.346	1.742		
			Avg	0.0293	0.0502	0.0249	0.382	1.796		
		Comparisons Ratio		1.15	1.19	0.83	1.06	1.00		
Skid Hyroll Road Load	30	Servo	Max	0.0271	0.0505	0.0286	0.498	2.075	12.85	152.9
			Min	0.0241	0.0436	0.0218	0.428	1.900	12.75	142.5
			Avg	0.0260	0.0482	0.0238	0.457	1.964	12.81	148.5
		Variable Dilution	Max	0.0310	0.0557	0.0233	0.496	2.197		
			Min	0.0260	0.0435	0.0176	0.439	2.050		
			Avg	0.0288	0.0448	0.0205	0.466	2.121		
		Comparisons Ratio		1.11	1.34	0.86	1.02	1.07		
Hybill Road Load	42	Servo	Max	0.0275	0.0460	0.0195	0.577	2.26	-2.55	184.8
			Min	0.0258	0.0375	0.0177	0.607	2.21	12.35	178.8
			Avg	0.026-	0.0406	0.0182	0.658	2.23	-2.49	181.4
		Variable Dilution	Max	0.0324	0.0726	0.0138	0.687	2.30		
			Min	0.0311	0.0600	0.0077	0.588	2.15		
			Avg	0.0315	0.0674	0.0129	0.656	2.21		
		Comparisons Ratio		1.18	1.15	0.71	1.0	0.99		

[a]Supporting data shown on Tables 2, 3, and 4 of Appendix A.

experimental cycle shown on Table 4, and simultaneous proportional samples were obtained by the servo and variable dilution methods. These experiments included level road and two uphill conditions to investigate the degree of agreement of the two proportional sampling techniques. Similar to Tables 4, 5, and 6, hydrocarbon emission results are listed as analyzed by NDIR and FIA on a pounds per mile basis. Similarly, NO_x as pounds of NO_2 per mile, CO as pounds of CO per mile, and CO_2 as pounds of CO_2 per mile are listed. Next, two operating parameters of interest, average air/fuel ratio and engine exhaust flow in standard cubic feet (SCF) per mile, are shown.

For the particular Class III truck reported, the data summarized in Table 7 indicate that the variable dilution sampler values were higher than those obtained via the servocontrolled sampler. This was true for hydrocarbons regardless of the operating condition, i.e., level road, slight uphill, or uphill load, or method of analysis, and is shown by comparison ratios, all greater than one, ranging from 1.0 to 1.06, indicating excellent agreement. This level of agreement was also noted for the CO_2 results with 0.99 to 1.07 comparison ratios. Oxides of nitrogen were consistently lower in the variable dilution samples with comparison ratios ranging from 0.71 to 0.86. To summarize, the poorest agreement was in the hydrocarbon data which were consistently higher and in the NO_x data which were lower with variable dilution.

Emissions data summarized in Table 7 are graphically depicted in Figure 11. The hydrocarbon, CO, CO_2, and NO_x data show the effect of a change in dynamometer power absorption setting for the nine-mode experimental Class III cycle, Table 5. In considering these curves, it should be recalled that the road load effect is of importance mainly during the constant speed cruise modes of the cycle, sequences 6 and 8. The part throttle acceleration, sequence 7, and wide open throttle acceleration, sequences 2, 3, and 4, are affected to a lesser extent. Except for the FIA hydrocarbons and CO_2 results, exhaust analyses of the samples from the two systems seemed to "track" and agree well as the load was varied.

An analysis of the emission trends using either or both sampling systems as a function of dynamometer setting may be made from Figure 11 with the aid of the operating data listed in Table 7. As the load was increased, the exhaust flow rate as well as the hydrocarbons and CO increased. At the same time, the engine air/fuel ratio indicated a richer mixture with increasing load. Of particular interest was the effect of load on NO_x in that an apparent maximum was reached at the slight uphill condition.

Two different Class IV vehicles were investigated using the twelve-mode experimental chassis dynamometer cycle described on Table 3. Two operating conditions were studied in detail for the 1966 IHC Class IV truck, namely, a level load (14 hp) and an uphill road load (19 hp). Shown on

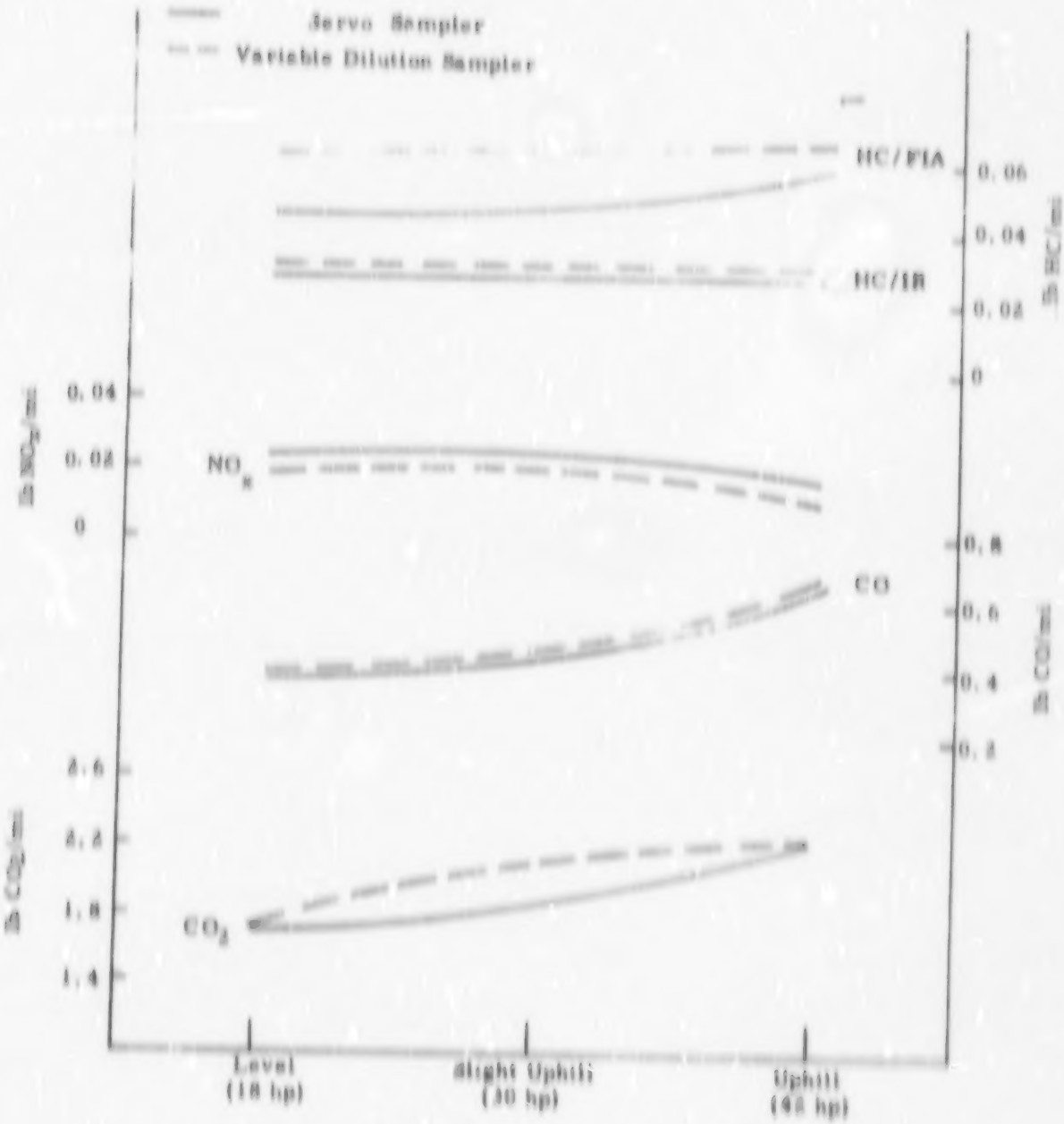

FIGURE 11. EFFECT OF ROAD LOAD DYNAMOMETER SETTING ON CLASS III 1965 VAN TRUCK EMISSIONS - EXPERIMENTAL NINE-MODE CYCLE

Table 8 are the summarized results for this vehicle using the same twelve-mode experimental cycle listed on Table 5. Using the comparison ratio as a guide, all exhaust emissions from this vehicle were higher with the variable dilution technique than with the servosampler. Unlike the Class III truck, the variable dilution emissions for this vehicle resulted in comparison ratios greater than 1.0 including the NO_x concentrations. The comparison ratio ranged from a minimum of 1.01 to a maximum of 1.13, with an overall average of 1.06 indicating a very close agreement between the variable dilution and servoproportional sampling techniques. Although only two load conditions were investigated, the general trend in emissions may be commented on. First, hydrocarbon mass emissions by both sampling techniques and both analysis methods were greater at the uphill than at the level road load condition. One exception was the FIA analysis of the variable dilution sampler. NO_x and CO_2 likewise increased. CO, however, was less at the higher road load. The engine air/fuel ratio was slightly less at the higher load condition indicating an overall slightly richer mixture which may have been involved in the higher HC, NO_x, and CO_2 experienced.

Shown on Table 9 are the results of a series of experiments with a 1967 stake body truck. These tests were conducted in the upper four speeds of the five-speed transmission (first gear was not used) with the rear axle ratio in "high speed" (low numerical ratio). The maximum, minimum, and average data on Table 8 are presented as in Table 7 for three load conditions. The comparison ratios indicate that the level of agreement between the variable dilution and servoproportional sampling techniques was closer than that shown on Table 7 for the Class III van. Overall, hydrocarbon values were greater with the variable dilution method than with the servoproportional method. The NO_x values were essentially the same by either sampling system with comparison ratios ranging from 0.93 to 0.98. Likewise, CO and CO_2 showed good agreement per ratios from 0.81 to 0.92 and 0.96 to 1.08, respectively. The comparison ratios were averaged by run condition, the overall ratio would be 0.98 for level road load, 1.05 for slight uphill, and 0.99 for uphill road load. These average comparison ratios indicate an excellent correlation between the two sampling systems.

On Figure 12, which is similar to Figure 11, the results listed on Table 9 are plotted by run condition. These plots graphically show the level of agreement between the two sampling systems and the similar results obtainable. As with the Class III truck, the CO and CO_2 increased with dynamometer road load settings. Unlike the Class III vehicle, however, the NO_x via proportional method increased to 0.0422 lb/mile from 0.0252 lb/mile as the load was increased. Hydrocarbon emissions measured by FIA decreased slightly with increasing load, while the NDIR hydrocarbons appeared to go through a peak at the midpower condition. It is interesting to analyze the emissions trends with the operating parameters of air/fuel ratio and engine exhaust flow rate in SCF/mile. As the road load was increased, the exhaust flow rate increased as expected. The air/fuel ratio, however,

TABLE 8. COMPARISON OF TWELVE-MODE EXPERIMENTAL CYCLE AT VARIOUS LOAD CONDITIONS TO ROAD COURSE EMISSIONS

Vehicle: 1966 Stake Truck, 24,000-lb GVW
Engine: 345-cu in. V-8

Fuel: Indolene
Cycle: See Table 3

Run Condition	Vehicle Power abs, hp	Proportional Sampling Method		NDIR THC, lb/mi	FIA THC, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/ Fuel Avg	Exhaust Flow, SCF/mi
Level Road Load	14	Servo	Max	0.0244	0.0498	0.0131	0.412	1.890	12.83	144.8
			Min	0.0229	0.0482	0.0125	0.426	1.812	12.75	148.5
			Avg	0.0236	0.0489	0.0127	0.421	1.844	12.79	142.7
		Variable Dilution*	Max	0.0252	0.0541	0.0201	0.456	2.095		
			Min	0.0245	0.0479	0.0161	0.406	1.890		
			Avg	0.0248	0.0517	0.0172	0.438	1.980		
		Comparison Ratio		1.05	1.06	1.35	1.04	1.07		
Uphill Road Load	19	Servo	Max	0.0250	0.0552	0.0216	0.418	2.570	13.17	189.8
			Min	0.0197	0.0434	0.0161	0.367	2.070	12.35	167.5
			Avg	0.0214	0.0478	0.0184	0.393	2.295	12.59	175.3
		Variable Dilution	Max	0.0247	0.0542	0.0208	0.427	2.575		
			Min	0.0240	0.0526	0.0161	0.372	2.370		
			Avg	0.0242	0.0532	0.0188	0.397	2.490		
		Comparison Ratio		1.13	1.11	1.02	1.01	1.08		

*Supporting data shown on Tables 2 and 3 of Appendix B.

TABLE 9. CLASS IV GASOLINE POWERED TRUCK TWELVE-MODE EXPERIMENTAL CYCLE EMISSIONS

Vehicle: 1967 Stake Truck, 14,000-GVW
Engine: 389-cu.in. V-8

Fuel: Indolene
Cycle: See Table 3

Run Condition	Vehicle Power abs. hp	Proportional Sampling Method		NDIR HSEC, lb/mi	FIA HSEC, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel Avg.	Exhaust Flow, SCF/mi
Level Road Load	12	Servo	Max	0.0192	0.0488	0.0260	0.161	2.14	13.7	150.0
			Min	0.0184	0.0464	0.0235	0.143	2.12	13.6	146.0
			Avg	0.0188	0.0478	0.0252	0.149	2.13	13.65	148.0
		Variable Dilution	Max	0.0219	0.0515	0.0269	0.130	2.05		
			Min	0.0195	0.0460	0.0206	0.122	2.04		
			Avg	0.0205	0.0496	0.0238	0.128	2.048		
		Comparison Ratio		1.09	1.05	0.95	0.86	0.96		
Slight Uphill Road Load	22	Servo	Max	0.0259	0.0605	0.0286	0.1715	2.10	13.4	159.0
			Min	0.0209	0.0392	0.0250	0.1615	1.73	12.95	155.0
			Avg	0.0235	0.0526	0.0277	0.1688	1.91	13.13	156.4
		Variable Dilution	Max	0.0293	0.0513	0.0309	0.175	2.16		
			Min	0.0252	0.0453	0.0246	0.151	2.05		
			Avg	0.0270	0.0484	0.0272	0.148	2.07		
		Comparison Ratio		1.15	1.11	0.98	0.92	1.08		
Uphill Road Load	34	Servo	Max	0.0224	0.0436	0.0449	0.2236	2.90	13.70	294.0
			Min	0.0203	0.0401	0.0398	0.2096	2.60	13.30	197.0
			Avg	0.0215	0.0419	0.0422	0.2215	2.82	13.55	281.0
		Variable Dilution	Max	0.0266	0.0492	0.0411	0.175	2.74		
			Min	0.0242	0.0410	0.0372	0.173	2.71		
			Avg	0.0252	0.0449	0.0391	0.174	2.73		
		Comparison Ratio		1.17	1.07	0.93	0.81	0.97		

*Supporting data shown on Tables 6, 9, and 10 of Appendix B.

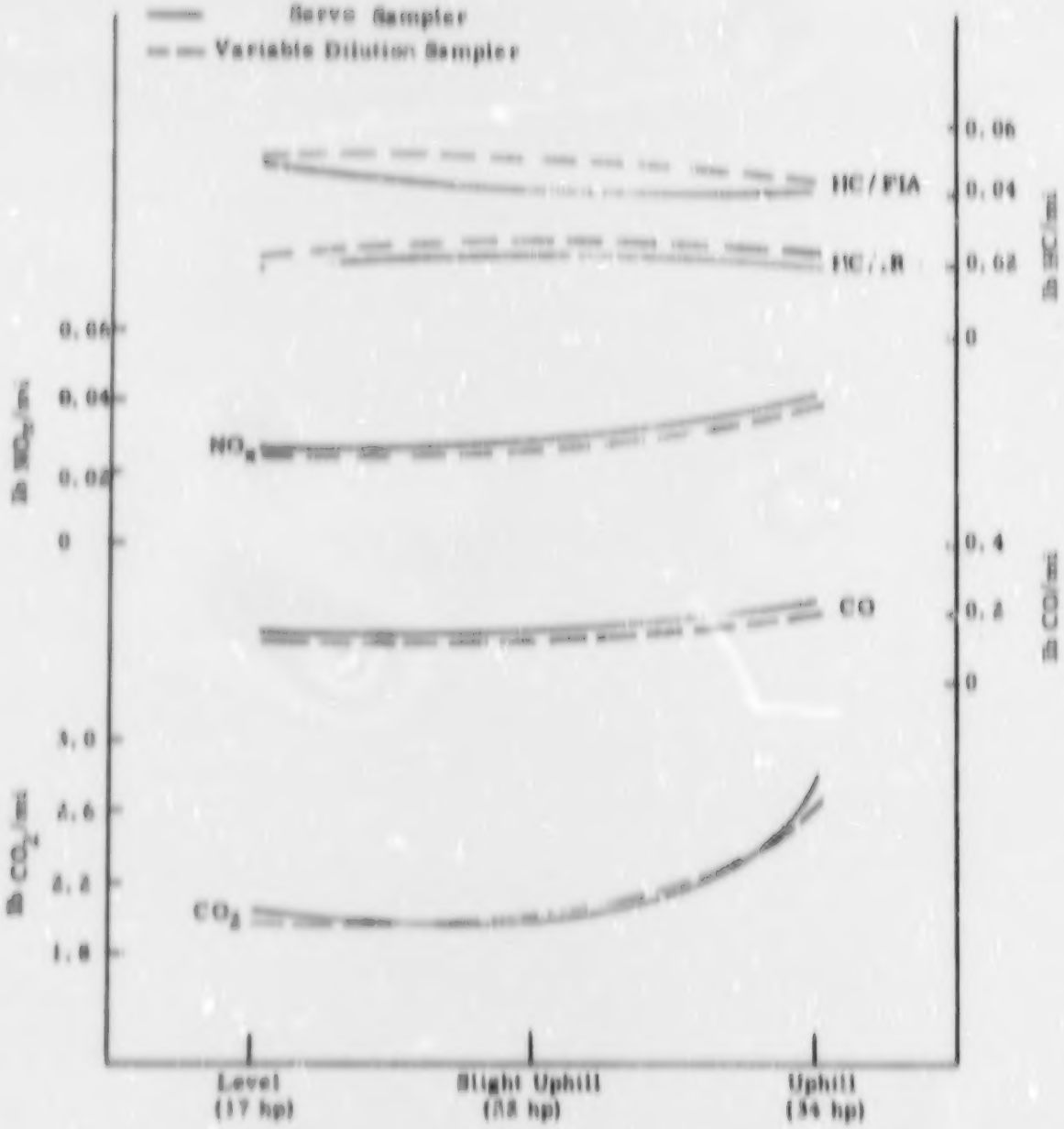

FIGURE 12. EFFECT OF ROAD LOAD DYNAMOMETER SETTING ON CLASS IV 1967 STAKE TRUCK EMISSIONS - EXPERIMENTAL TWELVE-MODE CYCLE

experienced a minimum of 13.13 at the slight uphill load; about 0.5 ratio less than at the level and uphill road load conditions. An apparent maximum hydrocarbon value, by NDIR, was recorded at the slight uphill load. The occurrence of maximum hydrocarbons during the richest overall mixture ratio of the three conditions may be easily explained. The CO_2 by the variable dilution method also went through a slight minimum condition at the slight uphill condition which agrees with the higher hydrocarbon production at this point. The FIA hydrocarbon trend and the NO_x and CO emissions curves do not show this effect except for a slight maximum at the mid-load condition noted for the FIA hydrocarbons by the servoproportional sampling system.

In summary, the level of agreement between the variable dilution and servocontrolled proportional sampling and analysis techniques was illustrated for a Class III vehicle operated on a nine-mode experimental cycle and for two Class IV vehicles operated on an experimental, twelve-mode cycle at several different road load dynamometer settings. The agreement between NDIR hydrocarbons, NO_x, and CO was satisfactory under all conditions investigated with the Class III 1965 van. Better agreement was obtained with the Class IV 1966 and 1967 stake trucks in all emission parameters measured. From this limited series of experiments, it appears that the variable dilution system is capable of obtaining suitable dilute samples of engine exhaust for determination of mass emissions and that these results agree sufficiently well with the proportional system. The variable dilution sampling system, like the proportional method, is sensitive to changes in vehicle operation as revealed by the Class III, 1965 van and Class IV, 1967 stake truck experiments. As a result, this type sampling system appears suited for the acquisition of baseline emissions from a variety of vehicles.

C. Proposed Constant Speed Federal Cycle Results Via Continuous and Variable Dilution Sampling

The final series of experiments involved emissions acquisition with the previously described vehicles under the proposed 1970 Federal Standard Heavy-Duty Gasoline Truck Cycle. The dynamometer procedure was described in Table I as a nine-mode, constant engine speed procedure. The results of these experiments are summarized in Table 10. Although samples were obtained simultaneously from each of the Class IV vehicles via the continuous sampling and analysis system and variable dilution sampler, no attempt was made to correlate the two.

Listed on the top half of Table 10 are the weighted HC and CO results determined during the simulated constant speed cycle at SwRI and the corresponding data taken from Reference 1 for the same two trucks. Comparing these two sets of data, the HC emissions were found to be higher and the CO concentrations to be lower than that previously reported. Shown on the

TABLE 10. PROPOSED 1970 FEDERAL STANDARD HEAVY-DUTY GASOLINE TRUCK CYCLE EMISSIONS

Cycle: Federal — Fuel: Indolene

Continuous Sampling Analysis by NDIR:

Weight Class	Vehicle Tested	HC/IR, ppm	CO, %	HC/IR, ppm	CO, %
III*	1965 Van 292 cu in. - six cylinder	270	1.20	336	2.82
IV†	1966 Stake 345 cu in. - V-8	404	1.10	419	2.56

PHS Variable Dilution Sampling:

Weight Class	Vehicle Tested	NDIR UBHC, lb/mi	FIA UBHC, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/ Fuel Avg.	Exhaust Flow, SCF/mi
III	1965 Van** 292 cu in. - six cylinder	0.0137	0.0221	0.0257	0.549	2.09	15.3	1121‡
IV	1966 Stake†† 345 cu in. - V-8	0.0145	0.0328	0.0150	0.233	1.79	13.9	1191‡

*Supporting data presented in Table 5 of Appendix A.
†Supporting data presented in Table 4 of Appendix B.
‡Exhaust flow measured with servoproportional sampling technique.
**Supporting data presented in Table 7 of Appendix A.
††Supporting data presented in Table 6 of Appendix B.

lower half of Table 10 are the emissions analyses of samples obtained by the variable dilution sampling method during operation of the two vehicles on the Federal constant speed cycle. Except for the 1965 van, the variable dilution samples were obtained simultaneously with the continuous NDIR sampling system results already discussed. It is not possible to compare the variable dilution results with the continuous sampling and analysis by NDIR cart results due to the different methods employed in computing and expressing the data.

It is of interest, however, to compare the variable dilution sampling and analysis data obtained during the Federal cycle with that obtained with the nonsteady speed experimental cycles. Shown on Table 11 is a comparison of these results for each of the two vehicles investigated. The Class III, 1965 van truck results are compared first and indicate that hydrocarbons were less with the Federal cycle than those obtained with any of the three road load conditions under the nine-mode experimental cycle. Oxides of nitrogen, however, were greater with the Federal cycle than any of the three load conditions investigated with the experimental cycle. CO, like unburned hydrocarbons, was also lower when the vehicle was operated on the Federal cycle than when it was operated under the nonsteady-state procedure. CO_2 mass emission appeared to be about the same during the Federal cycle and the experimental cycle at the slight uphill load condition. Air/fuel ratio was found to be higher (leaner) than the air/fuel ratios measured during the experimental cycle. The flow rate of exhaust from the engine was less with the Federal cycle than with the level road load experimental cycle.

Comparing the Class IV 1966 IHC stake truck Federal cycle and variable dilution results, it may be seen that hydrocarbons by NDIR and FIA, as well as CO, were noticeably lower than with those obtained during the experimental Class IV cycle. Oxides of nitrogen were only slightly lower for the Federal test cycle than for the experimental cycle. As in the case of the Class III truck, air/fuel ratio was higher, and exhaust flow was lower with the Federal test cycle.

Due to operational difficulties encountered in simulating the Federal cycle with the 1967 Chevrolet stake Class IV truck, the results from this limited test series are not included in this interim report. Additional Federal cycle tests are scheduled shortly with this particular Class IV vehicle, and the results will be included in a letter report.

TABLE II. COMPARISON OF VARIABLE DILUTION SAMPLING AND ANALYSIS RESULTS

Dynamometer Cycle	Run Condition	Vehicle Power, n+a, hp	NDIR UBHC, lb/mi	FIA UBHC, lb/mi	NO_{xp} lb/mi	CO, lb/mi	CO_2, lb/mi	Air/ Fuel Avg.	Exhaust Flow, SCF/mi
Weight Class III - 1965 Van, 292 cu in.*									
Federal	--	--	0.0137	0.0221	0.0257	0.269	2.050	13.30	112.0
Experimental	Level Road	18	0.0239	0.0602	0.0189	6.382	1.794	12.91	135.8
Experimental	Slight Uphill	30	0.0288	0.0648	0.0205	0.466	2.121	12.81	148.5
Experimental	Uphill	42	0.0315	0.0674	0.0129	0.656	2.210	12.49	180.4
Weight Class IV - 1966 Stake, 345 cu in.†									
Federal	--	--	0.0145	0.0328	0.0150	0.233	1.75	13.9	119.0
Experimental	Level Road	14	0.0248	0.0517	0.0174	0.438	1.98	12.79	142.7
Experimental	Uphill	19	0.0242	0.0332	0.0188	0.397	2.49	12.59	175.3

*Supporting data presented in Tables 2, 3, 4, and 7 of Appendix A.
†Supporting data presented in Tables 2, 3, and 6 of Appendix B.

VI. SUMMARY AND CONCLUSIONS

The following points summarize the important aspects of this interim report on the preparations made for acquisition of baseline emissions data from a number of gasoline powered trucks above 10,000-lb GVW. These remarks are made as a result of a study of emissions from the several representative vehicles utilized to establish correlation to previous work and between sampling systems:

(1) A number of experimental cycles were employed to investigate their effect, as well as to determine the sensitivity of the variable dilution and other sampling techniques to changes in operating variables. These cycles included basic, nine-mode Class III and twelve-mode Class IV experimental cycles with variations in road load simulation. These cycles, though experimental, appear realistic and are related to previously established road route patterns representative of the two classes of trucks above 10,000-lb GVW. The operational success and the repeatability of these experimental cycles appear to justify their use in obtaining baseline truck emissions data.

(2) Satisfactory correlation was demonstrated between the DLA road course results and the experimental cycle data via the simplified SwRI chassis dynamometer for the single Class III vehicle and the Class IV 1966 IHC stake truck at level road load power settings. The other Class IV vehicle correlated well with the previously obtained road data under an uphill road load power setting. As a result of these investigations, it was found that the Class III and Class IV chassis dynamometer cycles reported in Reference 1 could be employed in the simplified SwRI road simulation system with modifications. Using these adapted experimental cycles, a satisfactory level of agreement and correlation to that reported in Reference 1 was obtained.

(3) The level of agreement between the variable dilution and servo-controlled proportional sampling and analysis techniques was illustrated for a Class III vehicle operated on a nine-mode experimental cycle and for two Class IV vehicles operated on an experimental, twelve-mode cycle at several different road load dynamometer settings. The agreement between NDIR hydrocarbons, NO_x, and CO was satisfactory under all conditions investigated with the Class III 1965 van. Better agreement was obtained with the Class IV 1966 and 1967 stake trucks in all emission parameters measured. From this limited series of experiments, it appears that the variable dilution system is capable of obtaining suitable dilute samples of engine exhaust for

determination of mass emissions and that these results agree sufficiently well with the proportional system.

(4) The variable dilution sampling system, like the proportional method, is sensitive to changes in vehicle operation as revealed by the Class III, 1965 van and Class IV, 1967 stake truck experiments. As a result, this type sampling system appears suited for the acquisition of baseline emissions from a variety of vehicles.

(5) Results were obtained and presented using the proposed Federal Heavy Duty Gasoline Truck Cycle, by both the continuous NDIR sampling and analysis system, and the variable dilution technique. As no readily apparent means is available for the expression of emissions measurements on a mass basis using the currently proposed Federal Constant Speed Cycle and NDIR continuous system, no correlation of the two techniques is possible.

(6) Mass emissions data show that the constant speed cycle does not correlate with dynamometer test cycles established to simulate actual vehicle operation.

REFERENCES

1. "Exhaust Emission Analysis and Mode Cycle Development for Gasoline Powered Trucks," Ethyl Corporation Final Report to U. S. Public Health Service, Contract PH 86-66-150, September 1967.

2. Broering, Louis; Werner, William; and Rose, Andrew, "Automotive Mass Emission Analysis by a Variable Dilution Technique," presented at the Air Pollution Control Association Annual Meeting, Cleveland, Ohio, June 1967.

3. Springer, Karl and Williams, Glenn L., "Preparation of Truck Version PHS Variable Dilution Sampling System," Special Report to U. S. Public Health Service, Contract PH 86-67-72, March 1968.

4. Federal Register, Vol. 33, No. 2, Part II, Department of Health, Education and Welfare, January 4, 1968.

5. "California Test Procedure and Criteria for Motor Vehicle Exhaust Emission Control," California Motor Vehicle Pollution Control Board, 417 South Hill Street, Los Angeles, California 90013.

6. Federal Register, Vol. 31, No. 61, Part II, Department of Health, Education and Welfare, March 30, 1966.

7. Smith, R.; Rose, A. H.; and Kruse, R., "An Auto-Exhaust Proportional Sampler," International Journal of Air and Water Pollution, Vol. 8, pp. 427-440 (1964).

8. Springer, Karl J. and Stahman, Ralph C., "An Investigation of Diesel Powered Vehicle Odor and Smoke," National Petroleum Refiners Association Paper No. FL 66-46, September 15-16, 1966.

9. Springer, Karl J., "Special Status Report Covering Road and Chassis Dynamometer Operating Results for One Class III Vehicle and One Class IV Vehicle," August 23, 1967.

10. Springer, Karl J., "Special Status Report No. 2 Covering Road and Chassis Dynamometer Operating Results for 1967 Chevrolet C60 Truck No. C-7613R," January 5, 1968.

APPENDIX A

CLASS III TRUCK EXHAUST EMISSIONS RESULTS

1965 Chevrolet Van
292 cu in., I 6

TABLE A.1. CLASS III EXHAUST EMISSIONS FOR CORRELATION WITH DLA ROAD COURSE RESULTS

Vehicle: 1969 Chevrolet Van
Engine: 350-cu.in., six-cylinder
Date: September 5-6, 1967

Cycle: Experimental Nine-Mode
Sampler: Servoproportional
Fuel: Indolene

Load Condition	Run No.		HC (B), ppm C	HC (FID), ppm C	NO_x, ppm	CO, %	CO_2, %	HC (B), lb/mi	HC (FID), lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Acc/ Fuel Cyc	Acc/ Fuel CO_2	Acc/ Fuel Avg	Exhaust Flow SCF/mi
Level	1		5125	9610	1045	4.41	11.52	0.0259	0.0487	0.0176	0.415	1.855	13.00	12.60	12.80	140.5
	2		5871	9540	1054	4.68	11.61	0.0257	0.0452	0.0172	0.396	1.868	13.20	12.60	12.90	135.5
	3		5430	9750	1108	4.63	11.45	0.0261	0.0486	0.0182	0.405	1.805	13.10	12.55	12.80	138.5
	4		5360	9750	1151	3.82	11.58	0.0254	0.0410	0.0161	0.379	1.755	13.20	12.60	12.90	133.0
	5		5480	9850	1090	3.95	11.63	0.0262	0.0454	0.0173	0.376	1.746	13.25	12.70	13.00	134.2
		Max	5870	9750	1151	4.41	11.63	0.0257	0.0487	0.0182	0.415	1.855	13.25	12.70	13.00	140.5
		Min	5125	9750	1045	3.82	11.45	0.0259	0.0410	0.0172	0.376	1.746	13.00	12.55	12.80	133.0
		Avg	5549	9790	1099	4.09	11.54	0.0259	0.0455	0.0177	0.395	1.792	13.15	12.61	12.90	136.1
Right Cyclist	1		4752	8930	1340	3.77	11.41	0.0251	0.0419	0.0284	0.429	1.950	13.20	12.5	12.8	152.5
	2		4730	8760	1347	3.78	11.32	0.0245	0.0470	0.0299	0.430	2.250	13.30	12.4	12.8	154.5
	3		4859	8460	1415	3.75	11.25	0.0244	0.0461	0.0256	0.424	1.955	13.25	12.4	12.8	151.5
		Max	4859	8460	1340	3.78	11.41	0.0245	0.0470	0.0299	0.430	2.250	13.30	12.50	12.8	154.5
		Min	4730	8930	1415	3.75	11.25	0.0244	0.0419	0.0256	0.424	1.955	13.20	12.40	12.8	151.5
		Avg	4773	8380	1534	3.76	11.32	0.0257	0.0457	0.0280	0.424	2.05	13.25	12.40	12.8	153.5
Cyclist	1		7900	4400	900	4.94	10.92	0.0273	0.0489	0.0211	0.704	2.45	12.80	12.25	12.53	196
	2		7789	7420	1085	4.54	11.15	0.0270	0.0541	0.0240	0.611	2.34	12.90	12.40	12.65	184
	3		4071	7160	1245	4.60	11.25	0.0256	0.0490	0.0274	0.625	2.40	12.90	12.40	12.65	187
		Max	4275	7320	1245	4.94	11.25	0.0256	0.0541	0.0274	0.704	2.45	12.90	12.40	12.65	196
		Min	7420	4400	900	4.54	10.92	0.0270	0.0489	0.0211	0.611	2.34	12.80	12.25	12.53	184
		Avg	4000	7160	1080	4.69	11.10	0.0277	0.0506	0.0242	0.647	2.40	12.87	12.35	12.59	189

TABLE A.2. CLASS III EXHAUST EMISSIONS - ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1969 Chevrolet Van
Engine: 250-cu in., six-cylinder
Date: January 6, 1969

Cycle: Nonconventional Non-Hot
Fuel: Indolene

Run No.	Sampler	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Acr/ Fuel CO,	Acr/ Fuel CO_2,	Acr/ Fuel Avg,	Exhaust Flow, SCF/mi
1	Proportional	5240	9,854	1464	1.81	11.40	0.0262	0.0491	0.0244	0.384	1,810	13.20	12.40	12.80	176.3
2		4940	9,770	1420	1.69	11.53	0.0240	0.0486	0.0273	0.369	1,812	13.25	12.40	12.82	177.5
3		5480	10,160	1340	1.57	11.70	0.0264	0.0498	0.0218	0.362	1,810	13.30	12.57	12.95	176.3
4		5790	10,560	1363	4.47	11.70	0.0253	0.0396	0.0213	0.734	1,790	13.00	12.70	12.85	176.7
Max		5790	10,560	1464	4.42	11.70	0.0264	0.0498	0.0244	0.384	1,810	13.30	12.70	12.95	176.3
Min		4940	9,770	1340	1.57	11.40	0.0240	0.0736	0.0213	0.334	1,790	13.00	12.40	12.85	176.7
Avg		5413	10,086	1396	1.87	11.60	0.0255	0.0468	0.0237	0.362	1,799	13.19	12.64	12.91	176.9
1	Variable	274	440	51.7	0.170	0.560	0.0261	0.0449	0.0174	0.349	1,815				
2	Dilution	259	537	51.3	0.165	0.530	0.0257	0.0533	0.0176	0.349	1,742				
3		336	650	75.5	0.175	0.560	0.0312	0.0594	0.0257	0.460	1,815				
4		306	650	74.7	0.230	0.560	0.0310	0.0640	0.0132	0.472	1,805				
Max		336	650	75.5	0.230	0.560	0.0312	0.0594	0.0257	0.472	1,815				
Min		259	440	51.3	0.165	0.530	0.0257	0.0449	0.0132	0.349	1,742				
Avg		327	569	64.3	0.185	0.553	0.0285	0.0562	0.0180	0.382	1,794				

TABLE A.3. CLASS III EXHAUST EMISSIONS - SLIGHT UPHILL ROAD LOAD
CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE
DILUTION METHODS

Vehicle: 1965 Chevrolet Van
Engine: 292-cu in., six-cylinder
Date: January 10, 1968

Cycle: Experimental Slow-Mode
Fuel: Indolene

Run No.	Sampler	HC (CB), ppmC	HC (FIA), ppmC	NO_x, ppm	CO_2, %	HC (CB), g/mi	HC (FIA), g/mi	NO_x, g/mi	CO, g/mi	CO_2, g/mi	Acc. Fuel CO	Acc. Fuel CO_2	Acc. Fuel Avg.	Exhaust Flow, SCF/mi
1	Proportional	4720	9890	1390	3.99	11.33	0.9257	0.9476	0.6019	0.425	1.962	13.33	12.58	12.85	151.5
2		4403	7960	1347	4.51	11.40	0.8241	0.9434	0.6021	0.499	2.075	11.95	12.50	12.15	137.8
3		5150	9430	1385	4.19	11.55	0.9271	0.9585	0.6024	0.461	1.933	.00	12.40	12.80	146.3
4		5003	9460	1370	4.16	11.50	0.9234	0.9492	0.6056	0.459	1.903	.00	12.47	12.85	146.5
Max		5150	9890	1370	4.51	11.55	0.9271	0.9585	0.6056	0.499	.971	13.33	12.61	12.85	151.5
Min		4403	7960	1385	3.99	11.33	0.8241	0.9434	0.6019	0.425	.988	12.95	12.50	12.75	146.3
Avg		4822	9010	1374	4.24	11.45	0.9250	0.9492	0.6037	0.457	.944	13.36	12.55	12.81	146.5
1	Variable	336	635	55.0	0.235	0.66	0.0512	0.0540	0.0376	0.461	2.162				
2	Dilution	317	630	55.0	0.240	0.68	0.0549	0.0557	0.0376	0.476	2.197				
3		256	630	65.4	0.230	0.64	0.0504	0.0535	0.0372	0.466	2.050				
4		270	650	65.4	0.215	0.64	0.0473	0.0509	0.0372	0.439	2.055				
Max		332	650	65.4	0.240	0.68	0.0519	0.0557	0.0372	0.476	2.197				
Min		256	630	55.0	0.215	0.64	0.0504	0.0535	0.0376	0.439	2.050				
Avg		287	634	61.2	0.229	0.66	0.0509	0.0540	0.0374	0.446	2.121				

TABLE A.4 CLASS III EXHAUST EMISSIONS - UPHILL LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1961 Chevrolet Van
Engine: 250-cu in. six-cylinder
Date: January 11, 1968

Cycle: Experimental Nine-Mode
Fuel: Indolene

Run No.	Sampler	HC (B), ppm C	HC (FIA), ppm C	NO_x, ppm	CO, %	CO_2, %	HC (B), lb/hr	HC (FIA), lb/hr	NO_x, lb/hr	CO, lb/hr	CO_2, lb/hr	Acc/ Fuel CO	Acc/ Fuel CO_2	Acc/ Fuel Avg.	Exhaust Flow, SCF/min
1	Proportional	4700	9000	830	5.44	11.10	0.6264	0.8575	0.0377	4.700	2.26	12.45	12.40	12.35	178.0
2		3995	8420	805	1.32	10.50	0.5259	0.8042	0.0377	0.677	2.21	12.70	12.80	12.35	184.1
3		4060	8400	904	4.61	10.85	0.5254	0.8579	0.0345	0.647	2.34	12.90	12.20	12.50	180.5
4		4520	9120	831	4.82	10.90	0.6273	0.8641	0.0379	0.629	2.22	12.85	12.20	12.52	179.1
Max		4520	9120	904	5.44	11.10	0.6273	0.8641	0.0345	0.703	2.26	12.77	12.45	12.35	184.1
Min		3995	8400	805	4.61	10.50	0.6259	0.8575	0.0377	0.647	2.21	12.65	12.80	12.35	178.0
Avg		4324	9035	842	5.01	10.84	0.6264	0.8586	0.0362	0.659	2.23	12.77	12.20	12.49	182.4
1	Variable	312	670	45.6	0.34	0.68	0.0313	0.0620	0.0039	0.467	2.30				
2	Dilution	312	735	45.6	0.34	0.70	0.0317	0.0724	0.0039	0.664	2.22				
3		312	690	46.2	0.34	0.70	0.0311	0.0640	0.0032	0.456	2.15				
4		312	690	33.1	0.29	0.69	0.0324	0.0664	0.0077	0.568	2.17				
Max		312	735	46.2	0.340	0.70	0.0324	0.0724	0.0039	0.467	2.30				
Min		312	690	33.1	0.290	0.68	0.0311	0.0640	0.0077	0.568	2.15				
Avg		312	701	36.1	0.327	0.69	0.0315	0.0674	0.0029	0.459	2.22				

TABLE A.5. SUMMARY OF CLASS II EXHAUST EMISSIONS UNDER PROPOSED 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1965 Chevrolet Van
Engine: 292-cu in., six-cylinder
Date: February 29-March 1, 1968

Sampler: Continuous System
Cycle: Federal
Fuel: Indolene

Run No.	Emissions	Cold Cycle Avg	Hot Cycle Avg	Weighted Composite Avg
1	HC, ppm	279.2	308.9	289.1
	CO, %	3.07	3.23	3.17
2	HC, ppm	264.13	351.1	351.1
	CO, %	3.16	3.67	3.49
3	HC, ppm	250.87	340.47	344
	CO, %	3.05	3.36	3.36
4	HC, ppm	249.87	243.68	245.1
	CO, %	3.00	3.14	3.09
5	HC, ppm	206.2	237.2	231.5
	CO, %	2.97	3.24	3.13
6*	HC, ppm	240.23	258.54	251.7
	CO, %	3.02	3.46	3.33
7	HC, ppm	223.34	231.66	228
	CO, %	3.05	3.34	3.24
8	HC, ppm	211.16	227.3	221.5
	CO, %	3.10	3.41	3.29

*Most representative four-cycle concentration runs data presented in Table 6.

TABLE A.6. CLASS III EXHAUST EMISSIONS UNDER PROPOSED 1970 FEDERAL HEAVY-DUTY TRUCK PROCEDURE

(Representative Mode Data, Run 6)

Vehicle: 1965 Chevrolet Van
Engine: 292 cu in., six cylinder
Date: March 7, 1968

Cycle: Federal
Sampler: Continuous System
Fuel: Indolene

Cycle No. 1

Mode	HC	CO	CO_2	Gas Fac	HC Gas	CO Gas	HC WtFt	CO WtFt
1	235	3.17	8.65	1.195	280.8	3.783	10.11	0.151
2	145	0.65	14.00	1.053	150.6	0.868	13.40	0.061
3	140	0.80	15.84	1.066	148.4	0.836	37.66	0.416
4	107	0.39	16.05	1.047	112.0	0.516	9.97	0.067
5	165	1.15	14.00	1.024	168.9	0.117	7.95	0.096
6	100	0.83	14.06	1.053	105.3	0.868	9.57	0.021
7	173	7.20	10.6	1.074	185.8	7.732	56.58	2.188
8	65	2.60	14.10	1.085	67.1	0.014	7.75	0.065
9	5565	5.01	5.91	1.345	6670.1	5.134	95.91	0.107
Total							660.64	5.068

Cycle No. 2

1	235	8.17	8.65	1.195	280.8	9.763	10.11	0.151
2	105	0.55	14.00	1.036	108.8	0.562	9.68	0.056
3	107	0.78	14.06	1.036	110.8	0.748	28.47	0.196
4	65	0.65	14.35	1.027	67.5	0.610	7.77	0.056
5	165	1.05	14.00	1.058	166.3	0.104	7.96	0.067
6	95	0.60	14.00	1.035	98.5	0.66	5.74	0.036
7	165	7.60	10.50	1.065	172.6	7.753	68.79	2.188
8	75	0.65	15.95	1.065	78.6	0.079	6.98	0.060
9	5805	5.82	5.22	1.370	5614.8	5.888	109.46	0.109
Total							857.84	5.063
Average Cold Cycle Concentration							660.23	5.065

Cycle No. 3

1	605	9.65	7.24	1.205	688.0	11.68	17.86	0.418
2	105	0.56	14.10	1.037	108.9	0.559	9.69	0.049
3	110	1.00	14.00	1.067	113.0	1.027	29.04	0.265
4	95	0.75	15.95	1.066	99.0	0.781	8.81	0.069
5	260	1.75	13.65	1.015	261.0	1.776	11.45	0.085
6	95	0.52	15.20	1.033	98.1	0.537	8.73	0.047
7	165	7.60	10.50	1.046	172.6	7.940	68.89	2.190
8	95	0.75	14.10	1.032	98.0	0.774	8.72	0.068
9	4810	5.05	5.24	1.345	5385.4	5.170	115.09	0.108
Total							855.94	5.295

Cycle No. 4

1	605	9.65	7.24	1.205	688.0	11.66	17.90	0.418
2	130	0.70	14.95	1.042	135.5	0.749	12.06	0.064
3	120	1.35	13.82	1.027	12.33	1.386	31.05	0.356
4	115	0.75	14.00	1.027	118.1	0.970	10.51	0.086
5	170	0.50	14.10	1.014	175.8	0.517	8.26	0.024
6	90	0.65	14.07	1.043	93.9	0.669	8.36	0.041
7	165	7.67	10.60	1.049	173.1	7.856	68.99	2.217
8	95	0.78	14.07	1.032	98.0	0.804	8.74	0.071
9	6150	5.91	5.23	1.321	5484.1	5.165	115.12	0.108
Total							891.15	5.385
Average Hot Cycle Concentration							650.54	5.140

Four-Cycle Composite Emission
Hydrocarbon - 251.7 ppm
Carbon Monoxide - 5.235

TABLE A.7. CLASS III EXHAUST EMISSIONS UNDER PROPOSED 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1965 Chevrolet Van
Engine: 292-cu in., six-cylinder
Date: March 5, 1968

Sampler: Variable Dilution
Cycle: Federal
Fuel: Indolene

Run No.	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi
1	228	365	127	0.21	1.1	0.0135	0.0215	0.0250	0.250	2.960
2	228	365	150	0.21	1.1	0.0131	0.0209	0.0285	0.243	2.880
3	240	340	127	0.21	1.1	0.0143	0.0227	0.0252	0.254	2.985
4	240	400	127	0.21	1.1	0.0140	0.0234	0.0247	0.249	2.960
Max	240	400	150	0.21	1.1	0.0143	0.0234	0.0285	0.254	2.985
Min	228	365	127	0.21	1.1	0.0131	0.0209	0.0247	0.243	2.880
Avg	234	378	133	0.21	1.1	0.0137	0.0221	0.0259	0.249	2.946

APPENDIX B

CLASS IV TRUCK EXHAUST EMISSIONS RESULTS

1966 IHC Stake
345 cu in, V-8

1967 Chevrolet Stake
366 cu in, V-8

TABLE B.1. CLASS IV EXHAUST EMISSIONS FOR CORRELATION WITH DLA ROAD COURSE RESULTS

Vehicle: 1969 BMC Sedan
Engine: 345-cu.in. V-8
Date: September 6, 1967 and January 17, 1968

Cycle: Experimental Twelve-Mode
Sampler: Servoproportional
Fuel: Indolene

Load Condition	Run No.	HC (3), ppm C	HC (FTA), ppm C	W_{fp}, ppm	CO, %	CO_2, %	HC (3), lb/mi	HC (FTA), lb/mi	W_{fp}, lb/mi	CO, lb/mi	CO_2, lb/mi	Acc/ Fuel CO	Acc/ Fuel CO_2	Acc/ Fuel Avg.	Exhaust Flow, SCF/min
Level	1	4560	9100	732	3.93	11.15	0.0226	0.0462	0.0026	0.402	2.095	13.15	12.40	12.78	146.2
	2	4610	9640	738	4.13	11.25	0.0234	0.0491	0.0035	0.421	2.140	13.10	12.40	12.75	141.3
	3	4530	9570	732	4.17	11.46	0.0229	0.0484	0.0026	0.425	2.163	13.10	12.55	12.82	140.5
	4	4575	9530	751	4.05	11.40	0.0244	0.0498	0.0031	0.425	2.110	13.12	12.55	12.83	146.8
	Max	4675	9640	751	4.17	11.46	0.0244	0.0498	0.0035	0.425	2.140	13.15	12.55	12.83	146.8
	Min	4530	9100	732	3.93	11.15	0.0229	0.0462	0.0026	0.402	2.095	13.10	12.40	12.75	140.5
	Avg	4576	9520	744	4.09	11.32	0.0234	0.0469	0.0027	0.421	2.119	13.12	12.48	12.79	142.7
Slight Uphill	1	4175	8270	726	3.86	12.10	0.0234	0.0468	0.0033	0.467	2.19	13.2	12.90	13.05	157.5
	2	3470	7360	655	3.79	11.40	0.0196	0.0411	0.0031	0.429	2.05	13.2	12.90	13.05	156.5
	3	4580	9400	618	3.67	11.60	0.0263	0.0485	0.0034	0.426	2.22	13.3	12.95	12.98	144.5
	4	3910	8250	625	3.90	11.54	0.0221	0.0470	0.0028	0.448	2.13	13.2	12.90	12.90	142.5
	5	4280	8640	595	4.09	12.05	0.0265	0.0513	0.0030	0.481	2.48	13.1	13.25	13.18	165.5
	Max	4580	9640	726	4.09	12.10	0.0265	0.0513	0.0033	0.481	2.48	13.3	13.25	13.18	165.5
	Min	3470	7360	595	3.67	11.40	0.0196	0.0411	0.0028	0.426	2.05	13.1	12.90	12.85	156.5
	Avg	4083	8155	657	3.82	11.65	0.0236	0.0469	0.0032	0.454	2.19	13.2	12.79	13.00	160.0

TABLE B.2. CLASS IV EXHAUST EMISSIONS - ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1969 IHC Stake
Engine: 345-cu.in. V-8
Dau.: January 17, 1969

Cycle: Experimental Twelve-Mode
Fuel: Indolene

No.	Sample	HC(3), ppm C	HC(FTA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC(3), lb/hr	HC(FTA, lb/hr	NO_x, lb/hr	CO, lb/hr	CO_2, lb/hr	Acc/ Fuel CO	Acc/ Fuel CO_2	Acc/ Fuel Avg.	Exhaust Flow, SCFM
1	Proportional	4568	4,388	732	3.93	11.15	0.8439	0.8482	0.8535	0.462	2,095	11.15	11.48	11.78	346.3
2		4637	4,645	739	4.10	11.27	0.8724	0.8481	0.8535	0.421	2,148	11.19	11.48	11.75	345.3
3		4538	4,578	752	4.17	11.46	0.8529	0.8486	0.8539	0.425	2,167	11.19	11.55	11.82	345.5
4		4571	4,558	756	4.05	11.42	0.8596	0.8466	0.8515	0.425	2,110	11.12	11.55	11.80	346.9
Max		4571	4,645	751	4.17	11.46	0.8596	0.8466	0.8515	0.529	2,148	11.15	11.55	11.80	346.9
Min		4538	4,388	732	3.93	11.15	0.8529	0.8482	0.8535	0.462	2,095	11.19	11.48	11.75	345.3
Avg		4594	4,552	746	4.06	11.32	0.8529	0.8469	0.8527	0.421	2,130	11.12	11.48	11.79	342.7
1	Variable	236	580	46.2	0.33	8.57	0.0596	0.8529	0.8535	0.466	1,908				
2	Dilution	236	517	57.8	0.33	8.57	0.8596	0.8546	0.8535	0.466	1,908				
3		236	496	46.2	0.33	8.68	0.8597	0.8543	0.8544	0.485	2,895				
4		236	515	46.2	0.33	8.57	0.8552	0.8479	0.8544	0.485	2,835				
Max		236	515	57.8	0.33	8.68	0.8552	0.8546	0.8535	0.485	2,895				
Min		236	485	46.2	0.33	8.57	0.8596	0.8479	0.8544	0.485	1,908				
Avg		236	586	46.1	0.33	8.58	0.8548	0.8537	0.8572	0.478	1,768				

TABLE B.1. CLASS IV EXHAUST EMISSIONS - SLIGHT UPHILL RCAD LOAD
CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1984 IHC Model
Engine: 345-cu.in. V-8
Date: January 18, 1983

Cycle: Experimental Transient Mode
Fuel: Indolene

Run No.	Sampler	HC (3), ppmC	HC (FTA), ppmC	NO_x, ppm	CO, %	CO_2, %	HC (3), lb/hr	HC (FTA), lb/hr	NO_x, lb/hr	CO, lb/hr	CO_2, lb/hr	Acc/ Fuel CO	Acc/ Fuel CO_2	Acc/ Fuel Avg.	Exhaust Flow, SCFM
1	Proportional	3480	7470	675	1.35	11.72	0.0524	0.1675	0.0194	0.468	2.362	13.48	12.39	12.35	174.5
2		3675	8125	656	1.34	12.08	0.0253	0.1652	0.0224	0.424	2.378	13.58	12.85	13.17	184.0
3		3195	7486	662	1.34	11.38	0.0310	0.1661	0.0275	0.370	2.306	13.58	12.58	13.08	167.5
4		3251	7160	678	1.48	10.75	0.0317	0.1656	0.0242	0.367	2.070	13.58	12.15	12.82	146.2
Max		3480	8125	675	1.35	12.08	0.0524	0.1652	0.0224	0.468	2.511	13.58	12.85	13.17	184.0
Min		3195	7160	656	1.34	10.75	0.0310	0.1656	0.0242	0.367	2.070	13.48	12.15	12.35	167.5
Avg		3382	7561	671	1.385	11.48	0.0351	0.1678	0.0234	0.395	2.295	13.48	12.45	12.59	175.3
1	Variable	229	485	57.8	0.195	0.75	0.0024	0.0537	0.0039	0.427	2.575				
2	Dilution	228	515	57.8	0.175	0.75	0.0024	0.0542	0.0035	0.373	2.501				
3		226	495	46.2	0.175	0.71	0.0240	0.0529	0.0041	0.372	2.378				
4		228	500	46.2	0.195	0.75	0.0024	0.0579	0.0041	0.405	2.518				
Max		229	515	57.8	0.195	0.75	0.0240	0.0542	0.0039	0.427	2.575				
Min		226	485	46.2	0.175	0.71	0.0024	0.0529	0.0035	0.372	2.378				
Avg		228	500	52.0	0.185	0.74	0.0042	0.0552	0.0039	0.394	2.493				

TABLE B.4. SUMMARY OF CLASS IV EXHAUST EMISSIONS UNDER PROPOSED 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1966 IHC Stake
Engine: 345-cu in. V-8
Date: February 14, 15 and 20, 1968

Sampler: Continuous System
Cycle: Federal
Fuel: Indolene

Run No.	Emissions	Cold Cycle Avg	Hot Cycle Avg	Weighted Composite Avg
1	HC, ppm	316.53	523.31	456.50
	CO, %	2.84	3.12	3.02
2*	HC, ppm	444.44	534.63	402.0
	CO, %	2.96	3.045	3.01
3	HC, ppm	198.98	367.09	378.0
	CO, %	2.94	3.21	3.11
4	HC, ppm	350.43	377.24	366.50
	CO, %	3.06	2.98	3.00
5	HC, ppm	424.36	378.64	394.0
	CO, %	3.05	3.20	3.14
6	HC, ppm	305.59	277.79	287.3
	CO, %	2.76	3.12	2.99
7	HC, ppm	360.74	456.20	422.0
	CO, %	3.28	3.46	3.38
8	HC, ppm	451.07	404.58	419.5
	CO, %	3.42	3.31	3.35

*Most representative four-cycle concentration run data presented in Table 5.

TABLE B.5. CLASS IV EXHAUST EMISSIONS UNDER PROPOSED 1970 FEDERAL HEAVY-DUTY TRUCK PROCEDURE

(Representative Mode Data: Run 4)

Vehicle: 1966 IHC Stake
Engine: 345-cu in. V-8
Date: February 14, 1968

Cycle: Federal
Sampler: Continuous System
Fuel: Indolene

Cycle No. 1

Mode	HC	CO	CO_2	Gas Fac	HC Gas	CO Gas	HC WtD	CO WtD
1	1050	10.00	6.30	1.214	1674.7	14.14	65.89	0.451
2	410	1.76	13.80	1.015	515.8	1.76	18.97	0.156
3	150	1.92	13.75	1.014	188.1	1.94	59.09	0.498
4	150	2.56	13.40	1.021	193.8	2.60	16.54	0.213
5	135	3.47	12.85	1.021	170.7	3.54	8.40	0.106
6	150	1.78	13.70	1.017	192.5	1.81	13.58	1.61
7	150	3.56	12.65	1.034	194.4	3.68	18.03	1.061
8	150	1.95	13.33	1.043	195.5	2.03	15.07	1.79
9	1451	4.30	4.40	1.100	7970.1	4.73	167.50	0.899
Total							560.01	5.96

Cycle No. 2

1	1050	10.00	6.3	1.214	1674.7	14.14	65.89	0.451
2	405	1.77	13.90	0.998	404.8	1.76	55.97	0.156
3	350	1.86	13.95	0.998	349.5	1.81	89.77	0.465
4	345	2.62	13.32	1.085	374.3	2.87	55.31	0.455
5	305	3.20	13.07	1.085	352.6	3.47	10.57	0.163
6	295	2.00	13.70	1.085	320.1	2.11	28.49	0.191
7	260	3.02	13.05	0.990	257.4	3.58	78.86	1.015
8	235	2.10	13.50	1.024	240.8	2.14	41.37	0.190
9	9084	4.34	4.37	0.968	8791.3	4.20	184.61	0.088
Total							588.86	3.97
Average Cold Cycle Concentration							444.44	4.965

Cycle No. 3

1	1375	10.60	6.20	1.165	1601.9	14.84	57.67	0.461
2	550	4.15	13.85	0.988	543.6	4.14	66.60	0.188
3	375	1.98	14.04	0.975	365.6	1.93	93.95	0.496
4	360	2.85	13.76	0.997	358.9	2.84	51.96	0.199
5	345	3.80	13.34	1.005	346.7	3.81	16.69	0.111
6	340	2.50	13.70	0.993	337.7	2.48	28.27	0.240
7	310	5.05	12.75	0.998	401.5	5.04	115.68	1.086
8	310	4.47	13.66	1.002	309.4	4.47	27.54	0.208
9	8762	4.28	4.60	1.118	7857.6	4.76	158.28	0.099
Total							574.16	3.06

Cycle No. 4

1	1375	10.60	6.20	1.165	1601.9	14.84	57.67	0.461
2	490	4.06	13.90	0.987	483.7	4.01	65.04	0.180
3	390	1.79	13.95	0.998	389.6	1.78	100.02	0.497
4	355	2.56	13.40	1.021	362.5	2.61	52.26	0.208
5	345	3.87	13.40	0.999	344.6	3.87	16.19	0.154
6	335	2.46	13.76	0.994	332.9	2.44	29.63	0.217
7	310	5.00	13.10	0.998	308.5	5.76	58.95	1.054
8	195	2.30	13.57	1.007	196.5	2.31	17.47	0.205
9	7148	4.39	4.31	0.954	6781.0	4.18	148.40	0.087
Total							497.63	5.03
Average Hot Cycle Concentration							536.89	5.045

Four Cycle Composite Emission:
Hydrocarbon - 402 ppm
Carbon Monoxide - 5.01%

TABLE B.6. CLASS IV EXHAUST EMISSIONS UNDER PROPOSED 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1946 IHC Stake
Engine: 345-cu in. V-8
Date: February 14 and 15, 1968

Sampler: Variable Dilution
Cycle: Federal
Fuel: Indolene

Run No.	HC/IR, ppmC	HC/FIA, ppmC	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
1	221	345	92.5	0.145	0.75	0.01598	0.0246	0.0219	0.209	1.70	
2	240	380	104.0	0.145	0.83	0.01725	0.0272	0.0248	0.212	1.84	
3	192	455	57.6	0.160	0.73	0.01470	0.0347	0.0140	0.247	1.77	
4	180	440	46.1	0.150	0.71	0.01445	0.0353	0.0123	0.226	1.81	
5	180	365	69.4	0.150	0.72	0.01420	0.0298	0.0181	0.238	1.81	
6	216	420	46.2	0.150	0.68	0.01764	0.0343	0.0126	0.248	1.76	
Max	240	455	104.0	0.160	0.83	0.01760	0.0353	0.0249	0.248	1.84	
Min	180	345	46.1	0.145	0.71	0.01420	0.0246	0.0123	0.209	1.70	
Avg	205	401	69.3	0.150	0.74	0.01568	0.0310	0.0173	0.230	1.79	119

TABLE B.7. CLASS IV EXHAUST EMISSIONS FOR CORRELATION WITH DLA ROAD COURSE RESULTS

Vehicle: 1967 Chevrolet Step-
Engine: 396-cu.in. V-8
Date: January 2, 3, 4, and 5, 1968

Cycle: Experimental Twelve-Mode
Sampler: Semigrapectomatic
Fuel: Indolene

Load Condition	Run No.	HC (lb, gas/C	HC (DLA, gas/C	NO_x gas	CO, %	CO_2 %	HC (lb, lb/hr)	HC (DLA, lb/hr)	NO_x lb/hr	CO, lb/hr	CO_2 lb/hr	Air/Fuel (lb)	Air/Fuel (CO_2)	Air/Fuel Avg	Exhaust Flow, SCF/hr
Level	1	4050	7150	1490	1.470	12.35	0.1014	0.1081	0.0264	0.169	2.080	14.10	13.10	13.60	148.0
	2	3960	6810	1435	1.355	12.50	0.1002	0.1038	0.0251	0.154	2.096	14.20	13.15	13.70	146.5
	3	3280	6350	1360	1.370	12.45	0.0178	0.1045	0.0234	0.154	2.060	14.20	13.20	13.70	142.5
	4	3330	6250	1475	1.285	12.65	0.0158	0.1027	0.0254	0.127	2.108	14.25	13.30	13.78	145.9
	Max	4050	7150	1490	1.470	12.65	0.1014	0.1081	0.0264	0.169	2.080	14.25	13.30	13.78	148.0
	Min	3230	6250	1360	1.285	12.35	0.0148	0.1027	0.0234	0.127	2.060	14.10	13.10	13.60	142.5
	Avg	3680	6740	1425	1.368	12.55	0.0164	0.1048	0.0252	0.154	2.111	14.19	13.24	13.68	147.5
Right Turn	1	3440	6460	1.38	1.460	12.50	0.0155	0.0994	0.0251	0.1658	2.24	14.15	13.15	13.65	156.5
	2	4250	7250	1470	1.405	12.38	0.0215	0.1406	0.0289	0.1645	2.22	14.15	13.08	13.57	155.7
	3	3940	7220	1670	1.485	12.45	0.0161	0.1294	0.0346	0.1675	2.24	14.15	13.20	13.68	155.3
	4	3770	4950	1790	1.705	12.45	0.0155	0.1071	0.0359	0.1595	2.21	14.15	13.19	13.70	155.0
	Max	4250	7250	1670	1.485	12.45	0.0215	0.1406	0.0346	0.1675	2.240	14.15	13.20	13.70	156.5
	Min	3770	4950	1470	1.705	12.38	0.0155	0.1071	0.0289	0.1595	2.210	14.15	13.08	13.57	155.0
	Avg	3975	5960	1648	1.401	12.46	0.0169	0.1033	0.0306	0.1619	2.225	14.15	13.11	13.64	155.5
Moderate Turn	1	3970	5400	1730	1.615	12.45	0.0152	0.0833	1.0556	0.1791	2.42	14.07	13.10	13.70	170.1
	2	3710	4740	1860	1.525	12.50	0.0149	0.0245	0.0582	0.145	2.46	14.10	13.10	13.70	172.0
	3	3911	5910	1940	1.340	11.90	0.0174	0.0373	0.0340	0.152	2.24	14.10	12.80	13.45	171.1
	4	3830	5180	1875	1.530	12.55	0.0173	0.0540	0.0535	0.204	2.49	14.10	13.15	13.57	170.0
	Max	3970	5400	1875	1.615	12.55	0.0152	0.0833	0.0582	0.204	2.49	14.10	13.15	13.70	172.0
	Min	3710	4740	1860	1.525	11.90	0.0149	0.0245	0.0340	0.145	2.24	14.07	12.80	13.45	170.0
	Avg	3830	5120	1795	1.553	12.35	0.0174	0.0531	0.0540	0.741	2.39	14.09	13.06	13.61	170.9
Typ.II	1	3545	5360	2075	1.480	12.87	0.0179	0.0542	0.0472	0.2440	2.65	14.10	13.35	13.70	186.5
	2	3420	4640	2140	1.423	13.17	0.0179	0.0534	0.0439	0.222	2.50	14.10	13.40	13.71	185.1
	3	3485	4845	2004	1.465	13.10	0.0174	0.0529	0.0439	0.215	2.48	14.15	13.80	13.47	184.5
	4	3515	4855	1946	1.755	13.27	0.0159	0.0551	0.0430	0.206	2.47	14.15	13.10	13.57	186.5
	Max	3545	5360	2075	1.755	13.27	0.0179	0.0542	0.0472	0.2440	2.65	14.15	13.35	13.71	186.5
	Min	3420	4640	1946	1.423	13.17	0.0159	0.0534	0.0430	0.206	2.47	14.10	13.40	13.47	184.5
	Avg	3491	4725	1915	1.531	13.15	0.0172	0.0539	0.0445	0.233	2.53	14.12	13.41	13.61	185.9

TABLE B.8. CLASS IV EXHAUST EMISSIONS – ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1987 Chevrolet Sprint
Engine: 79[illegible] cu. in. V-8
Date: March 28, 1988

Cycle: Experimental Twelve-Mode
Fuel: Indolene

Run No.	Sampler	HC/TR, ppmC	HC/TFA, ppmC	NO_x, ppm	CO, %	CO_2, %	HC/TR, lb/mi	HC/TFA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Arr/ Fuel CO	Arr/ Fuel CO_2	Arr/ Fuel Avg	Exhaust Flow, SCFM
1	Proportional	3470	5640	1465	1.315	12.4	0.0154	0.0664	0.0250	0.143	2.14	14.7	13.2	13.70	[illegible]
2		3450	5740	1460	1.470	12.4	0.0151	0.0684	0.0253	0.161	2.12	14.1	13.1	13.65	150
3		3540	5640	1310	1.395	12.5	0.0152	0.0689	0.0225	0.145	2.11	14.2	13.1	13.64	151
4		3540	5760	1465	1.350	12.7	0.0149	0.0676	0.0256	0.147	2.12	14.2	13.3	13.70	149
Max		3540	5760	1465	1.470	12.70	0.0154	0.0689	0.0261	0.161	2.14	14.7	13.3	13.70	151.0
Min		3450	5640	1310	1.395	12.40	0.0149	0.0664	0.0225	0.143	2.11	14.1	13.1	13.64	146.0
Avg		3477.5	5762	1425	1.39	12.55	0.0149	0.0679	0.0252	0.149	2.13	14.2	13.2	13.67	148.0
1	Tem/Vac	252	460	91.4	0.055	0.40	-.0007	0.0078	0.0041	0.122	2.05				
2	Dilution	246	475	96.7	0.063	0.40	0.0038	0.0512	0.0026	0.130	2.05				
3		240	460	91.4	0.060	0.40	0.0015	0.0460	0.00[illegible]	0.130	2.06				
4		264	480	91.4	0.060	0.40	0.0019	0.0515	0.00[illegible]	0.130	2.05				
Max		264	480	91.4	0.060	0.40	0.0019	0.0515	0.0049	0.130	2.06				
Min		240	460	91.4	0.055	0.40	0.0015	0.0460	0.0026	0.122	2.05				
Avg		250.5	494	94.5	0.059	0.40	0.0026	0.0499	0.0036	0.128	2.06				

TABLE B.9. CLASS IV EXHAUST EMISSIONS - SLIGHT UPHILL ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1947 Chevrolet Sedan
Engine: 90hp s.c. 6-cyl
Date: March 18, 1948

Cycle: Experimental Twelve-Mode
Fuel: Indolene

Run No.	Location	HC (3), ppm C	HC (FID), ppm C	NO_x, ppm	CO, %	CO_2, %	HC (3), lb/hr.	HC (FID), lb/hr.	NO_x, lb/hr.	CO, lb/hr.	CO_2, lb/hr.	Air/Fuel, CO	Air/Fuel, CO_2	Air/Fuel, Avg.	Exhaust Flow, SCF/min.
1	Proportional	4100	6750	1460	1.445	11.38	0.3210	0.5405	0.6274	0.3439	7.10	14.1	12.7	13.40	131.7
2		4850	7470	1441	1.431	10.15	0.3711	0.5823	0.6279	0.3346	6.87	14.2	12.9	13.55	136.8
3		4775	7460	1520	1.465	10.79	0.3742	0.5948	0.7036	0.3703	6.91	14.1	13.1	13.10	137.1
4		5160	7830	1435	1.349	9.75	0.3936	0.5992	0.6534	0.3419	6.71	14.2	13.7	13.95	135.8
Max		4100	6750	1520	1.465	11.38	0.3210	0.5405	0.6534	0.3703	7.10	14.2	13.7	13.40	136.8
Min		5160	7830	1435	1.349	9.75	0.3936	0.5992	0.7036	0.3419	6.71	14.1	12.7	13.95	135.8
Avg		4588	7128	1464	1.422	10.44	0.3650	0.5792	0.6531	0.3477	6.90	14.2	12.9	13.50	135.4
1	Variable	338	445	85.8	1.368	0.40	0.0291	0.0408	0.0262	0.175	2.87				
2	Dilution	311	440	85.8	1.341	7.33	0.0270	0.0411	0.0180	0.169	2.84				
3		301	440	84.4	1.343	8.33	0.0252	0.0403	0.0206	0.168	2.83				
4		324	420	85.4	1.348	8.33	0.0274	0.0403	0.0204	0.170	2.85				
Max		338	445	85.8	1.368	8.40	0.0291	0.0413	0.0268	0.175	2.87				
Min		301	420	84.4	1.343	7.33	0.0252	0.0403	0.0204	0.170	2.85				
Avg		314	443	75.2	1.354	8.38	0.0271	0.0408	0.0272	0.168	2.87				

TABLE B.III. CLASS IV EXHAUST EMISSIONS - UPHILL ROAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1967 Chevrolet Sedan
Engine: 396-cu. in. V-8
Date: March 21, 1968

Cycle: Experimental Twelve Mode
Fuel: Indolene

Run No.	Sample	HC(13), ppm C	HC(FID), ppm C	NO_x, ppm	CO, %	CO_2, %	HC(13), lb/hr	HC(FID), lb/hr	NO_x, lb/hr	CO, lb/hr	CO_2, lb/hr	Air/Fuel, CO	Air/Fuel, CO_2	Air/Fuel, Avg.	Exhaust Flow, SCFM
1	Proportional	3170	6,160	1440	1.565	12.70	0.0224	0.0429	0.0769	0.224	2.87	14.1	13.2	13.65	197
2		2970	5,750	1615	1.465	12.20	0.0211	0.0402	0.0849	0.204	2.66	14.1	12.9	13.50	204
3		2790	5,580	1720	1.480	11.40	0.0201	0.0401	0.0918	0.206	2.68	14.2	12.4	13.30	201
4		2940	5,670	1750	1.470	12.60	0.0212	0.0410	0.0921	0.205	2.90	14.2	13.2	13.70	201
Max		3170	6,160	1815	1.565	12.70	0.0224	0.0429	0.0949	0.224	2.95	14.28	13.2	13.70	204
Min		2790	5,580	1440	1.465	11.40	0.0201	0.0401	0.0769	0.206	2.66	14.10	12.4	13.30	197
Avg		2968	5,770	1758	1.470	12.23	0.0211	0.0421	0.0922	0.215	2.82	14.15	13.0	13.56	201
1	Tunnel	312	460	115	0.55	0.80	0.0224	0.0402	0.0410	0.173	2.71				
2	Diverter	305	420	104	0.55	0.80	0.0216	0.0404	0.0372	0.175	2.74				
3		299	395	104	0.54	0.80	0.0201	0.0403	0.0372	0.174	2.74				
4		295	420	115	0.55	0.80	0.0242	0.0440	0.041..	0.174	2.72				
Max		312	460	115	0.55	0.87	0.0244	0.0440	0.0411	0.175	2.74				
Min		295	395	104	0.54	0.80	0.0242	0.0403	0.0372	0.173	2.71				
Avg		297	420	109	0.55	0.80	0.0221	0.0409	0.0391	0.174	2.73				